REBALLASTING THE KC-135 FLEET FOR FUEL EFFICIENCY

THESIS

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Abstract

The KC-135 was subject to numerous changes over its first 50 years of service as it has adapted to new and expanded mission requirements. These changes have added a large amount of weight to the aircraft, much of it focused in the rear of the airframe which created an aft Center of Gravity (CG). Boeing accounts for this aft CG by requiring that ballast fuel be carried in the forward body tank to maintain a CG forward of the aft limit.

An Engineering Analysis (EA) recently performed by Boeing states that 3,500 lbs of fuel is to be left in the forward body tank strictly for ballast, with no other purpose. Using fuel in the forward body tank for ballast has two significant drawbacks; the forward body tank has a very short moment-arm necessitating more weight than that of ballast on a longer moment-arm, and ballast fuel displaces fuel that could be used for mission purposes by using the tank to hold ballast weight.

Reducing aircraft gross weight is a cost issue, because excess weight incurs a “carriage cost”. The “carriage cost” for weight on the KC-135 is 4.97% of the weight in pounds of fuel burned per hour. This thesis focuses on the cost recoupment horizon for reballasting the KC-135 fleet and whether the cost will justify the fuel efficiency and increased mission capability. Specifically, this research examines replacement of fuel ballast with lead ballast on a longer moment arm and/or weight with a mission purpose, in the form of cockpit armor, to minimize ballast weight requirements. This will reduce aircraft gross weight and generate increased fuel efficiency.

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To my loving wife, my two sons,

to the crews who have maintained and flown the KC-135 for more than a half century

and those who will fly the mighty "Stratotanker" well into the coming decades.

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Major Dan Mattioda, for his guidance and support throughout the course of this thesis effort and to my technical reader Lt Col Christopher Shearer. Their insight and experience was certainly appreciated. I would, also, like to thank my sponsor, Col Kevin “Nuke” Trayer, from the Air Mobility Command, Fuel Efficiency Office for both the support and latitude provided to me in this endeavor.

I am also indebted to the KC-135 Systems Group who provided me with much of the vital data needed to make this project a reality and to Mr. Michael Lombardi, the Boeing Corporate historian who supplied me with a lot of the original KC-135 technical data. Special thanks go to Mr. Gary Mott, who always took time out of his busy schedule to answer all my tough KC-135 questions and his active solicitation of others to do the same.

Philip G. Morrison

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REBALLASTING THE KC-135 FLEET FOR FUEL EFFICIENCY

I. Introduction

Background, Motivation and Problem Statement

The KC-135 aircraft has and continues to be crucial to the modern defense of the United States (Hopkins, 1997: 11). Despite the tanker recapitalization effort, better known as the "KC-X" program, the KC-135 is projected to continue as a vital and viable provider of global air refueling through FY 2040 with the help of the KC-135 Aircraft Extension Program (AEP) (Air Mobility Command, 2008: 80).

The history of the KC-135 is punctuated by numerous modifications that resulted in a heavier and more poorly ballasted aircraft (Hopkins, 1997: 35-50). The means of maintaining aircraft Center of Gravity (CG), within prescribed longitudinal requirements, hinges on the use of fuel to provide ballast trim (Boeing Aero, 2009: 70). Recent analysis by Boeing has identified a strict requirement to maintain 3,500 lbs of fuel in the forward-most tank (Forward Body Tank), specifically to meet this requirement (Boeing Aero, 2009: 3). Prior to this study, Boeing asserted that the aircraft not be operated below 7,000 lbs total fuel, undoubtedly a combination of fuel required to feed engines and ballast the airframe, but with no explanation of the fuel's specific purpose (Boeing, 2009).

The use of "tankered fuel" to provide ballast is horribly inefficient because it utilizes a very short moment-arm to balance the aircraft; this requires a greater amount of weight than that of ballast applied to a longer moment-arm. Additionally, using fuel to

ballast the airframe renders the fuel unusable, because it must be present for the entire flight or the aircraft will reach an unsafe aft CG. This unusable ballast fuel displaces other-wise usable fuel that could increase mission capability if the aircraft needs to be loaded to tank capacity.

The surge in oil prices in 2007, increasing global pressure to limit Green House Gas (GHG) emissions, and national desire to decrease foreign energy dependence led to a nation-wide reexamination of energy consumption. The charge was led by non-other than President George W. Bush on January 24, 2007 when he signed Executive Order 13423 (EO 13423) (Bush, 2007: 3-7). The goals set forth in EO 13423, by the President, were reasserted most recently by the Secretary of the Air Force (SECAF), Michael B. Donley in his Air Force Policy Memorandum 10-1 (AFPM 10-1) dated June 16, 2009. Secretary Donley stated, in AFPM 10-1, "the Air Force goal of reducing aviation fuel-use per hour of operation by 10% (from a 2005 base line) by 2015" (Donley, 2009: 9).

Executive Order 13423, AFPM 10-1 and numerous other similar decrees from the civilian leadership have spurred research into the use of aviation fuel and the development of programs to mitigate fuel use by the Air Force and other branches of the military. One such research project was conducted by Cyintech, a defense contractor hired by Air Mobility Command (AMC), to calculate the Cost of Weight (CoW) for their fleet of mobility aircraft. The results from this research were astounding; in the case of the KC-135R the CoW was determined to be an average of 4.97% per hour (Cyintech, 2008: 8). This average CoW was determined by averaging the excess fuel burned for weight carried on short, medium and long duration flights (short flights are subject to a higher hourly burn rate penalty and longer flights subject to a lesser burn rate). This

means on average that for every 100 lbs of weight loaded onto the aircraft 4.97 lbs of fuel are required to keep it airborne for 1 hour, in the case of just a 5 hour flight almost 25 lbs of fuel are required to transport 100 lbs! The knowledge of CoW and restrictions levied upon the service led to an AMC-wide effort to eliminate excess weight from its aircraft (Kelly, 2007: 1). Although, many weight reduction efforts were started before Cyintech's results were published, the merit of weight reduction was determined earlier through benchmarking the airline industry, the results from Cyintech armed AMC policy makers with a quantifiable metric.

One of the earlier pursuits by AMC was a thorough examination of fuel loading on mobility aircraft. This was a logical starting point because it could be enacted quickly and yield large increases in efficiency. AMC hired a consultant to help translate the airline industry's efforts into a plan that could be executed in the Air Force. This consultant was Mr. Jim Barnes, a United Airlines pilot who helped develop the fuel efficiency programs at United. He helped model the AMC investigation of fuel efficiency after that of United and other commercial airline carriers.

As part of the fuel loading examination, the Subject Matter Experts (SMEs) for each of AMCs aircraft were asked to dissect the fuel loaded onto their aircraft and determine its specific purpose. While most of the fuel loaded onto each airframe was very strictly regulated and well defined, what differed significantly were the manufactures' definitions of when the respective aircraft were empty. In the case of the KC-135 the minimum landing fuel, as determined by Boeing, was 7,000 lbs of fuel (Boeing, 2009), far more than any other aircraft in the mobility fleet including much larger aircraft like the C-5 aircraft. This discovery spurred the Air Force to order an

examination by Boeing into the purpose for such a high “zero fuel” weight. See Table 1 for list of frequently used terms and their definitions.

Table 1. List of Terms

Zero Fuel Weight	Minimum fuel weight required for safe operation of aircraft, includes fuel required for ballast and engine feeding, fuel level below this will result in engine flameout and/or unsafe center of gravity
Weight Ballast	Weight applied at the forward most position strictly for the purpose of ballasting the airframe
Equipment Ballast	Equipment added to the forward portion of the aircraft that serves to ballast the airframe
Trim Ballast	Weight Ballast added to achieve the aft CG constraint, this weight is in addition to Equipment Ballast for those aircraft that require it
Tankered Fuel	Fuel transported from point of departure to destination, for convenience or follow-on mission requirement, but not designated for burn on current mission leg

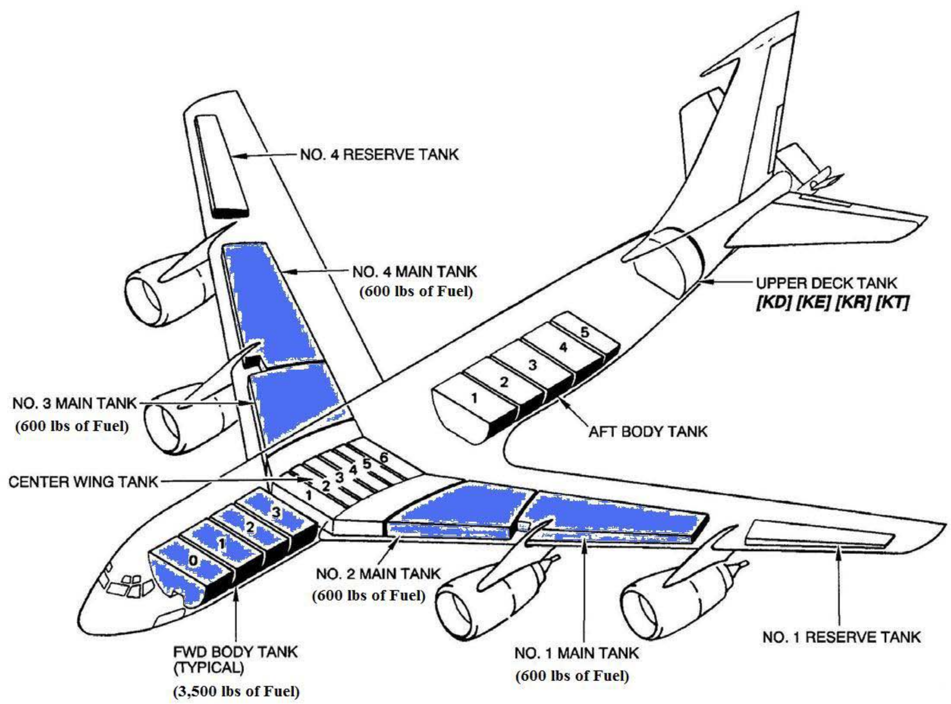
The examination of KC-135 “zero fuel” was conducted by Boeing Aero as Engineering Analysis (EA) 08-043-135AMC and it is the results of this analysis that confirmed the suspicions of the crews that had been flying the KC-135. The crews had been hauling fuel around simply to balance the aircraft and keep it from tipping on its tail. One such crewmember who suspected this was the case, Lt Col Lanson Ross, went so far as to propose a solution. He suggested instead of carrying fuel in the forward body, the Air Force examine placing weights in the nose of the aircraft, this “weight ballast” will take advantage of a longer moment-arm and decrease total weight required, similar to the way the KC-135T was ballasted for its configuration (see discussion in Literature Review) (Ross, 2008: 1).

Unfortunately, when Lt Col Ross proposed his solution the fuel carried on the KC-135 as ballast had not been delineated as such and many of his “rough estimates” could not be substantiated. The results of EA 08-043-135AMC in 2009 paved the way

for a serious examination of his proposal and it is the combination of the two that serve as the cornerstone to this project (Boeing Aero, 2009: 70).

Figure 1 depicts the tanks requiring fuel for compliance with the “zero fuel” configuration that evolved from EA 08-043-135AMC. Guidance Memorandum (GM) 1 for 11-2-KC-135 Volume 3 released November 2, 2009 reduced “zero fuel” weight from 7,000 to 5,900 lbs (600 lbs in each of the 4 main tanks to prevent boost pump cavitation/engine flameout and 3,500 lbs in the forward body tank for ballast). It is the 3,500 lbs in the forward body tank that this investigation specifically targets for removal from the “zero fuel” requirement.

Figure 1. Current “Zero Fuel” Configuration (Boeing, 2009)



Eliminating weight from the aircraft and mitigating the waste of substantial quantities of fuel is very exciting, especially when you consider the order of magnitude of simple changes and their massive contribution to the goal set forth by the SECAF. An

additional possibility is using equipment, which enhances the aircraft mission and ballasts the aircraft. The idea of making constructive use of ballast weight is even more fascinating. This “equipment ballast” could be achieved by adding equipment in a strategic position so as to both ballast the plane and enhance the mission by providing increased capability. The concept of adding equipment on an aircraft and incurring the subsequent weight penalties has long been regarded as a necessary evil, for mission accomplishment. The penalty often serves to curtail the addition of certain equipment when it is deemed cost prohibitive. The aerospace industry at large is acutely aware of this and as a consequence endeavors to find lighter and lighter materials to reduce this “cost of ownership” for their customers.

The “equipment ballast” option is somewhat unique, because the opposite would be true, if equipment was placed appropriately. It could be considered that adding weight with the appropriate moment-arm has a relative “negative carriage cost” because it allows for the elimination of excess ballast fuel, which only serves as “dead weight”. This appropriately placed “equipment ballast” would net a fuel cost mitigation and serves to enhance mission capability. This is one of the fascinating possibilities that this project will consider. In the case of the KC-135, such equipment would have to meet a couple of key constraints; it would have to be placed far enough forward to take advantage of an extended moment-arm and it would have to be heavy enough to contribute significantly to the ballast of the plane and subsequent weight reduction. While “weight ballast” can prevent the expense of fuel waste, increase payload capability, minimize pollution and GHG emissions; “equipment ballast” can do all this and provide additional mission capabilities.

One candidate for "equipment ballast" that appears to present itself as an option, by nature of its weight and required station location on the flight deck, is cockpit armor. While studies have been conducted to examine the feasibility of adding armor to the KC-135 flight deck (Boeing Aero, 2002: 1-4), cockpit armor was ironically dismissed because of its added weight and cost.

Although the equipment ballast option offers additional mission capability it will have some drawbacks when considered against the weight ballast option. Weight ballast will allow for the longest moment-arm, which will require the least amount of ballast weight, resulting in the greatest gross weight reduction. The cost of installing simple weight, whether it is lead, depleted uranium or some other form of dense material, represents a slightly cheaper manner of balancing the aircraft than installing equipment for the purpose of ballast. Additionally, if equipment ballast is used a small portion of the fleet will still require weight ballast be added to "trim-out" remaining aircraft balance requirements. A careful consideration of mission value must be weighed against the initial cost outlay required for equipment ballast to determine its value as an option.

The costs associated with both weight ballast and equipment ballast options and the recoupment horizons for aircraft modification and equipment purchase will be calculated to frame the discussion. The outlay of funds is critical to any investment, but the relationship between initial cost and return on investment is of greater concern. This investigation is not just about making a simple financial argument; it involves money, mission capability, environmental impact and compliance with stated goals. The unusual possibility that exists here is the potential to align these desperately different and quite often competing objectives and potentially make a case for all or most of them at least in

part.

The fact that the KC-135 is a “legacy aircraft” is not ignored in this examination. It is for this reason that “recoupment horizons” are the focus of the financial examination so they can be considered against future service life of the KC-135 airframe. It is the fact that the KC-135 is an “old workhorse” knitted into the fabric of military strategy that makes this study so crucial. Implications for a range of strategic missions must be considered, especially those that could significantly benefit from the increased offload capability of up to 3,500 pounds of fuel per KC-135 mission!

Assumptions and Limitations

This study is built upon numerous Engineering Analyses (EAs) which have made examination of this subject possible. Without the delineation by EA 08-043-135AMC of what fuel was required for what purpose on the aircraft, it would be impossible to discuss eliminating ballast fuel. It would be equally difficult to calculate fuel costs associated with excess weight without the research conducted on CoW for the KC-135 or to discuss adding cockpit armor without the weight and moment data that came from EA 02-048-135OTH. The feasibility and costs associated with cockpit armor are in fact known, it was even tested on the KC-135 airframe. The current cost of a KC-135 cockpit armor kit, as advertised by QinetiQ North (the manufacturer of LAST armor) is $82,500 (recurring cost) with a non-recurring engineering cost of $82,500 (coincidentally the cost of one kit) (Norris, 2010). The cost estimates for armor will be calculated using these quotes.

Ballasting the nose of the KC-135 is also not an original concept, and has been proven to work for almost 50 years on the KC-135Q (now T-models). Unfortunately, the

engineering data from the original feasibility study has not survived and cost data; even if it did exist, would be misrepresentative five decades later. It can be assumed that station 178 (the location which represents the bulkhead at the radome) is capable of handling a minimum of 850 lbs of ballast (since this is the amount previously added to the Q model)(Hopkins 1997), but there is no guarantee that this station can support weight in excess of that amount. Station 178 can be seen in Figure 2 as the position where the radome attaches to the aircraft just forward of the cockpit.

Stations are measured in inches from a reference point which is 130 inches forward of the tip of the aircraft nose. The stations depicted in Figure 2 are referred to throughout this study. Figure 3 is an expanded view of the wing section that shows the relationship between station location and Mean Aerodynamic Chord (MAC). The leading edge of the MAC is 786.2 inches aft of the reference point, hence, located at station 786.2. MAC is 241.9 inches long, so the aircraft CG constraints of 18% MAC (forward CG limit) and 35% MAC (aft CG limit) coincide with stations 829.742 and 870.865 respectively. For all regimes of flight and aircraft loads examined in this investigation, as long as the CG is between these two stations the aircraft will be safe to operate. It is the aft CG constraint of 35% MAC that garners the most attention in this study because it is the most difficult to achieve at light weights due to the current configuration of the KC-135 airframe.

Figure 2. KC-135 Station Locations (Boeing, 2009: 3-4)

AIRPLANE DIAGRAM (TYPICAL)

NOTE

- Inches from reference datum identical to station numbers. Landing gear retraction moment change negligible.
- Leveling device – Plumb bob at station 932.37 in LH main wheel well.
- Jig point – Use any leveling pad at station 178, 360, 620, or 1240.

❶ Inboard wing jacking cones are at sta 801.9 and at sta 810.5.

❷ Tail jacking cone at sta 1507 is on right side, with a capacity of 24,000 pounds.

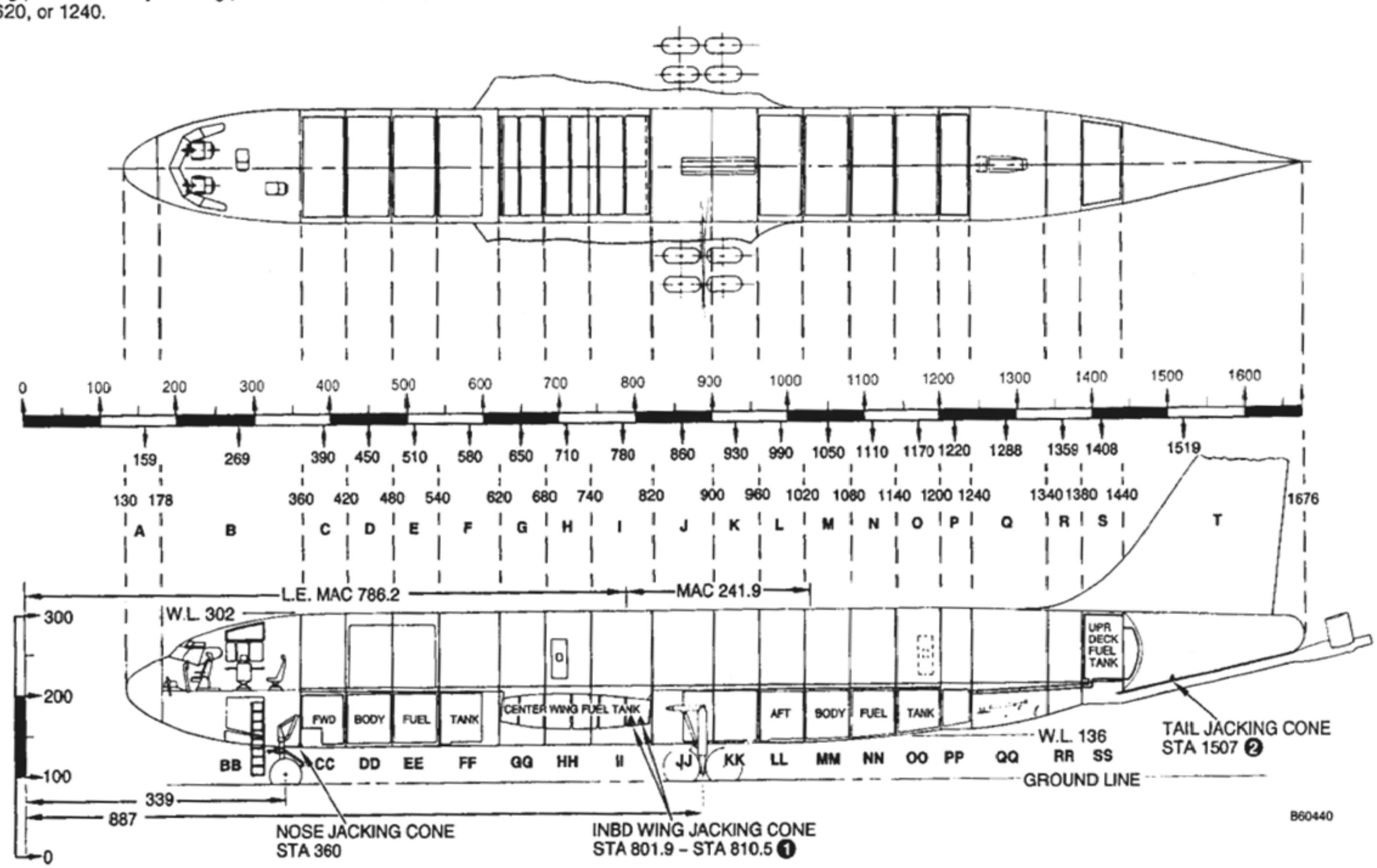
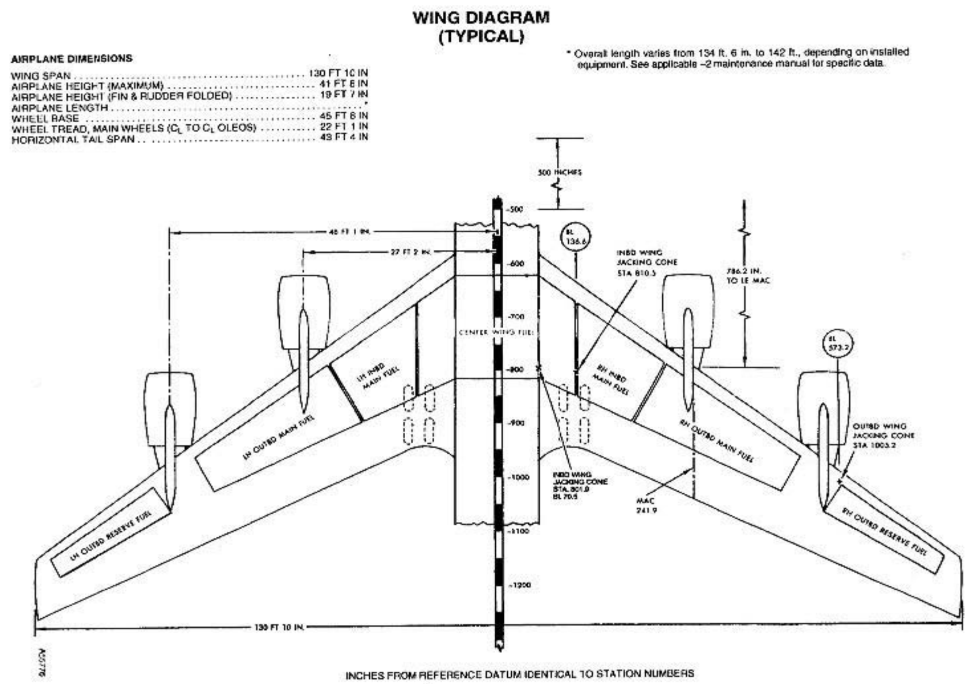


Figure 3. Station Location Relative to Mean Aerodynamic Chord (MAC)

(Boeing 2009: 3-4)



At this time the Boeing Corporation is engaged in an EA (EA 09-031-135AMC) to determine the feasibility of adding nose ballast to the KC-135 at station 178 up to 1,800 lbs with instructions to determine the next forward-most position and its capacity, if it is found that station 178 cannot handle that amount. Additionally, the feasibility study will deliver a cost estimate for accomplishing the reballasting project. Since the

results of the analysis by Boeing are not scheduled for release until after this study is released, a cost estimate is used for analysis. This analysis assumes a capacity of 1414 lbs of ballast at station 178 (under the radome), enough to satisfy the worst ballasted KC-135 in the fleet with a minimum fuel load (600 lbs per main tank). If this assumption is discovered to be false, for the purpose of implementation additional ballast should be placed in the location furthest forward with capacity, there are ample options with similarly long moment-arms in the proximity of station 220.

The cost estimate developed for this study is based on the assumption that modification would be conducted during aircraft scheduled depot maintenance. An estimate of KC-135 depot maintenance cost (FY08) is $230/hour (Boyd, 2010), based on a 200 man-hour completion estimate per aircraft, labor can be projected at $46,000. If engineering costs, above those already funded in the existing EA, are rolled into materials, which consist of simple metal brackets, ballasting material (lead, depleted uranium or any other appropriately dense material) nuts, bolts and washers, a conservative estimate would be $5,000 per aircraft. The sum of labor and parts/engineering totaling $51,000 is used as an estimate for applying ballast at station 178 throughout this analysis regardless of the amount of weight applied to the individual airframe.

The calculation of fuel mitigation will be primarily conducted in terms of pounds of fuel. Fuel estimates will be converted to a fuel cost mitigation value for the purpose of calculating recoupment horizons. The (FY10) price of JP-8 aviation fuel effective January 1, 2010 is $3.22 a gallon (or $0.47 per pound) (Defense Energy Support Center, 2010) and will be used throughout this analysis.

The estimate of KC-135 flying hours per year is based solely on past flying hours reported by the 618th Tanker Airlift Control Center (618 TACC), the global air operations center responsible for execution of the Air Force mobility fleet. The 618 TACC/XOND recorded 200,367 KC-135 flying hours globally (FY08), this number can be treated as a conservative estimate due to a substantial year over year growth in flying hours (618 TACC/XOND, 2009).

Today's KC-135 fleet is horribly ballasted due to numerous modifications that have resulted in a tail heavy aircraft. The current solution to this problem is to leave fuel in the forward body tank to compensate. This study looks at alternate solutions to this problem that will reduce overall aircraft operating weight and increase mission capability and effectiveness.

Chapter 2 presents a literature review of the KC-135 and Chapter 3 details research methodology used to examine alternate solutions, the results and analysis of the study are presented in Chapter 4, followed by a discussion of the information gleaned from the research in Chapter 5.

II. Literature Review

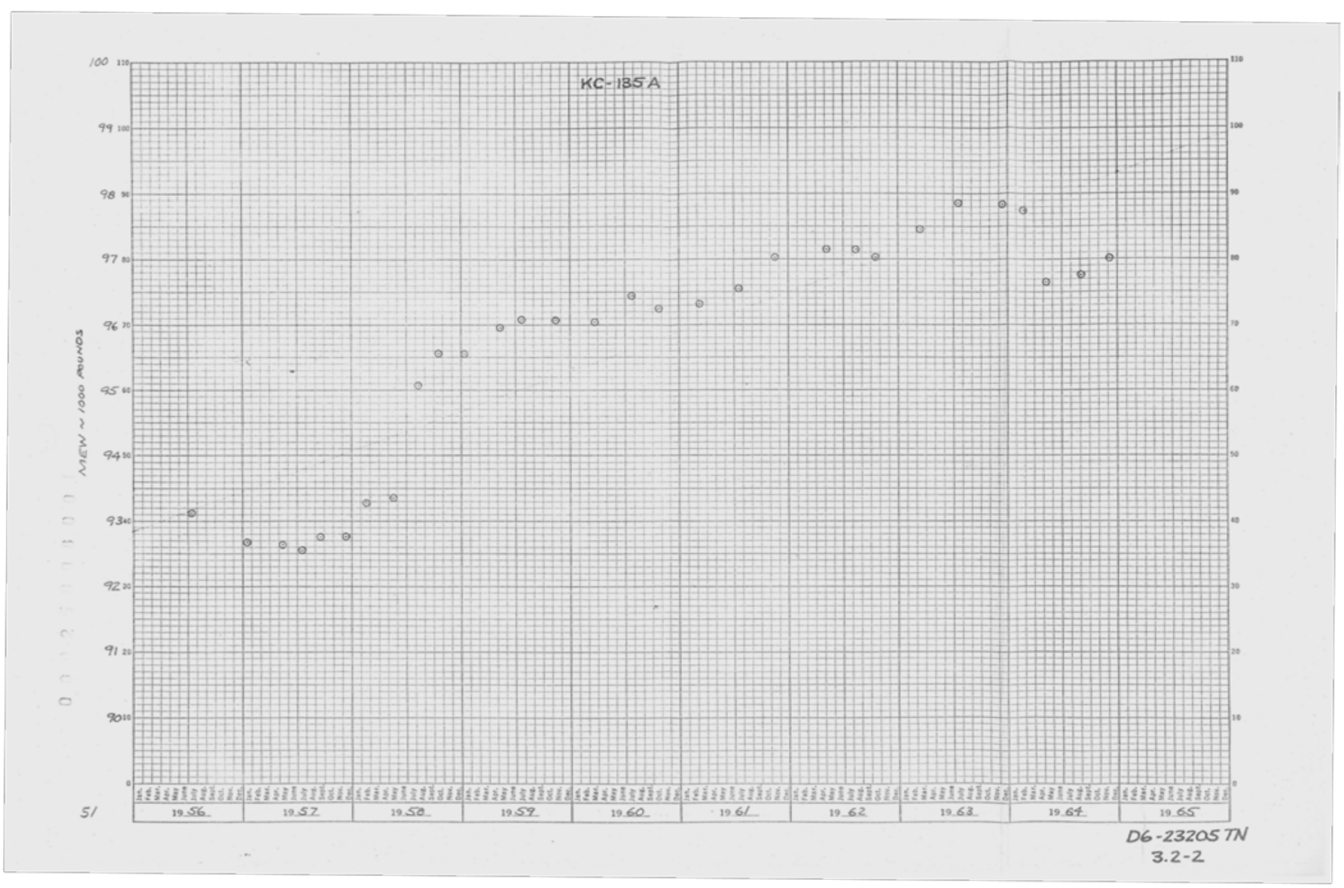
The KC-135R as an airframe has evolved over the course of 55 years. The Boeing 367-80 or "Dash-80" was the prototype of both the KC-135 and Boeing 707. Since the Dash-80's first flight, July 15, 1954 (Schiff, 1967: 3-5) numerous changes have been made to the airframe. These changes have led to greater operational capability, keeping it a viable platform as requirements have changed, but many changes have also increased the weight and changed the airframe balance.

The KC-135A had a production basic weight of 97,000 lbs, equipped with its J57-P-43W titanium engines (Hopkins, 1997: 35), but average basic weight of the USAF KC-135R fleet in 2009 is 119,213 lbs (excluding Multi-Point Refueling System (MPRS) aircraft which have an average basic weight of 120,370 lbs) and the average basic weight of a KC-135T is 120,293 lbs (Boeing, 2009).

Even in the very beginning of the KC-135 production cycle, Boeing engineers were cognizant of the rapidly increasing weight of the “Stratotanker”. Table 2 developed by Boeing in 1965, shows the growing average weight of the KC-135A over the first 10 years of production.

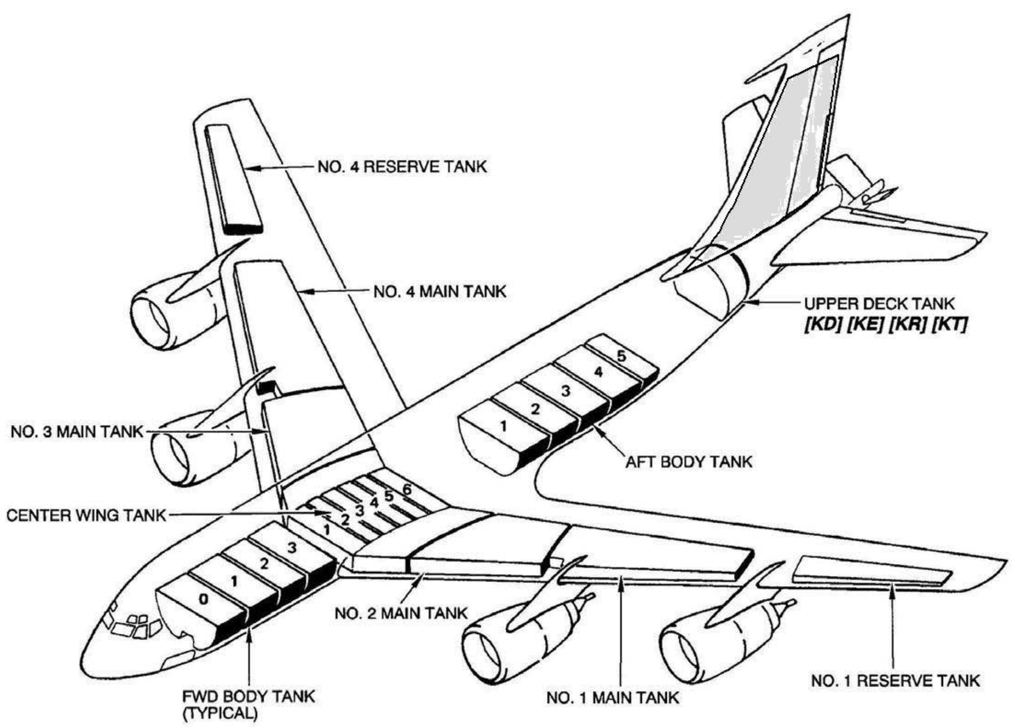
Table 2. Mean Aircraft Weight Growth During First Ten Years

(Boeing Aircraft Corporation, 1965)



The weight gain experienced by the KC-135 airframe over the course of its 55 year life cannot be attributed to any one event. The changes made to the airframe during the conversions from KC-135As to KC-135Rs and KC-135Qs to KC-135Ts were significant, but they were neither the first nor the last changes that had major impact on this weight issue. One such major modification made to the KC-135 was in 1962, when "Boeing engineers redesigned the vertical stabilizer, increasing its height by 40 in[ches] and increasing the surface area of the rudder" (Hopkins, 1997: 40). This modification was made to increase lateral control, but added weight to the tail with a long moment-arm shifting CG further aft. Figure 4 shows the smaller original tall (shaded) superimposed over the current "tall tail".

Figure 4. Tail Modification (Boeing, 2009)



Other structural improvements were made to reinforce the aircraft tail structure in the early years. The addition of sonic straps or "belly bands" in 1958 stiffened the aft fuselage, an area prone to sonic stress from the J57 engines during water injection, by bonding "25 circumferential bands 2in (5cm) wide … onto the exterior of the airplane aft of the wing root" (Hopkins, 1997: 40).

In 1966 the development of the SR-71, which burned PF-1 fuel, required the redesignation and reengineering of 21 KC-135As turning them into KC-135Qs, to provide the newest spy plane with PF-1 air refueling support (later an additional 33 aircraft were converted for a total of 54). The fuel system on these new "Q-models" allowed for separation of PF-1 from JP-4, the fuel burned by the KC-135's J57 engines, in the "Q-model" tanks. In addition to replumbing the aircraft to prevent fuel mixing, ceramic tank liners were added to the KC-135Q body tanks "impervious to PF-1, adding considerable weight to the aircraft" (Hopkins, 1997: 68-69). "To account for changes in the airplane's center-of-gravity (cg) during SR-71 refueling operations, 850 lbs (385Kg) of ballast was added to the lower nose compartment" (Hopkins, 1997: 69) this counteracted the added weight associated with these heavy ceramic panels. Later the ceramic panels were removed, but the 850 lbs of ballast remain on the KC-135Q aircraft. The "Q-models" were then subject to many of the same modifications that the rest of the KC-135 fleet experienced. The 850 lbs of ballast served to counteract the aft CG tendency that many of these modifications introduced.

Despite reengining, which changed the designation of the KC-135Q to the KC-135T, the addition of dual APUs and all of the structural changes that her "R-model" sisters also experienced the KC-135T model today has an average CG of 35.3% MAC (at

basic weight) (Boeing, 2009). This, when compared to the average 37.5% MAC (at basic weight) found in the KC-135R fleet, is very well balanced; especially when one considers that the KC-135 dash-1 aft CG limit is 35% MAC for almost all flight regimes (Boeing, 2009).

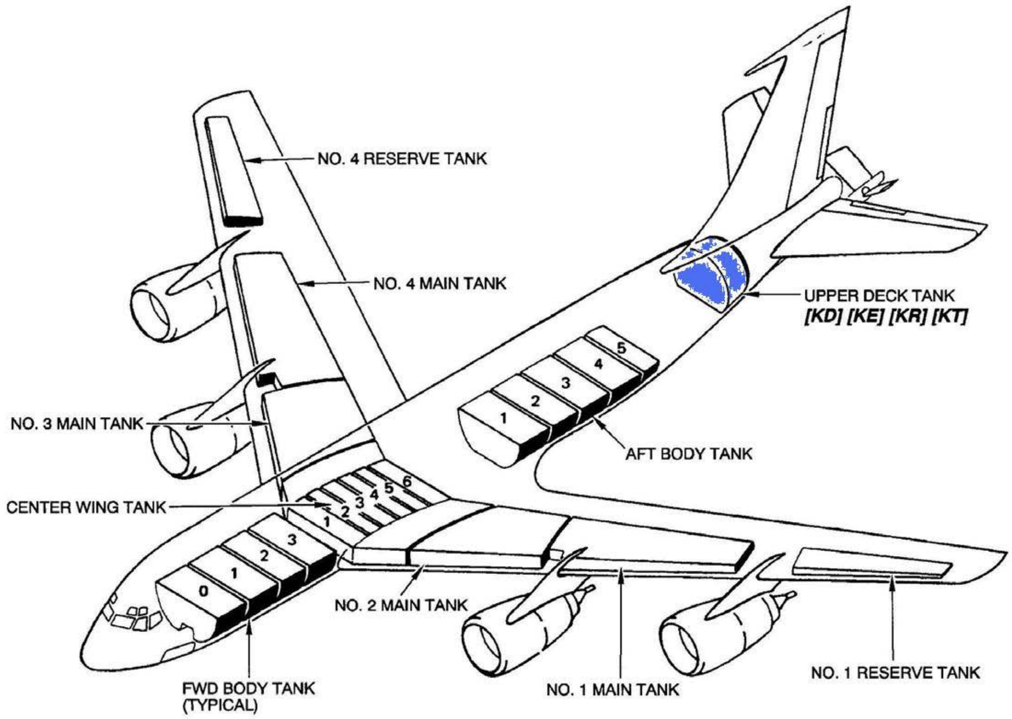
The major modifications made to the KC-135A and KC-135Q models during their conversion to KC-135R and KC-135T models were the addition of the CFM56-2 (F-108 military designation) engines, increased surface area on the horizontal stabilizers and the addition of new bigger APUs (Hopkins, 1997: 71). The original KC-135A engines were Pratt & Whitney J57-P-29W turbojet engines which are rated at 12,100 lbs of thrust (Smithsonian Air and Space Museum, 2009: A19810155000), installed on the first three aircraft only; followed by J57-P-31W, J57-P43W and finally J57-P/F-59W (Hopkins, 1997: 43-44). It was the heavier J57-P/F-59W that was eventually replaced during “A to R-model” conversion with CFM International CFM56-2 turbofan engines, rated at 22,000 lbs of thrust (Smithsonian Air & Space Museum, 2009: A19900042000). This increase in vital thrust and fuel efficiency increased the KC-135 offload capability from 40,000 lbs of fuel on a 4,000 mile round trip mission to 70,000 lbs of fuel (Hopkins, 1997: 71), but the engines also added weight to the airframe.

The J57-P-43W turbojet engine, which became the standard production engine, was built out of titanium and weighs approximately 400 lbs less than the original (Flight Magazine, 1959: 408) J57-P-29W engine, which was built out of steel and weighs 4,285 lbs (Smithsonian Air & Space Museum, 2009: A19810155000). It was with the titanium J57-P-43W engine, weighing approximately 3,885 lbs, that the KC-135 achieved its light production weight of 97,000 lbs. The eventual replacement of this power plant with the

far more powerful and heavier CFM56-2 turbofan engine, which weighs 4,635 lbs (Smithsonian Air and Space Museum, 2009: A19900042000), resulted in a 750 lb increase in weight per engine or a 3,000 lbs net gain in gross weight for all four engines. While this explains 3,000 lbs of the weight gain atop the airframe's production baseline weight, it does not appear to have contributed to the aircraft's aft CG, since the engines are located approximately at the aircraft's 35% MAC. Specifically, engines 1 and 4 are slightly aft of the 35% MAC and engines 2 and 3 are located slightly forward of the 35% MAC (Boeing, 2009: 3-3 - 3-4).

The most likely culprits in the aircraft's aft CG problems are the modifications made near the tail. The addition of the dual APUs during reengining (see Figure 6) and the addition of the upper deck tank (see **Error! Reference source not found.**) are prime candidates for scrutiny. Although these modifications were not the largest weight additions to the airframe, the associated moment-arms are very long, amplifying their effect on the aircraft's CG. The upper deck fuel tank which has an empty bladder weight of 92 lbs (station 1414.3) has an average moment 543 inches aft of the 35% MAC (station 870.8). **Error! Reference source not found.** shows the location of the upper deck fuel tank (shaded) relative to the rest of the airframe.

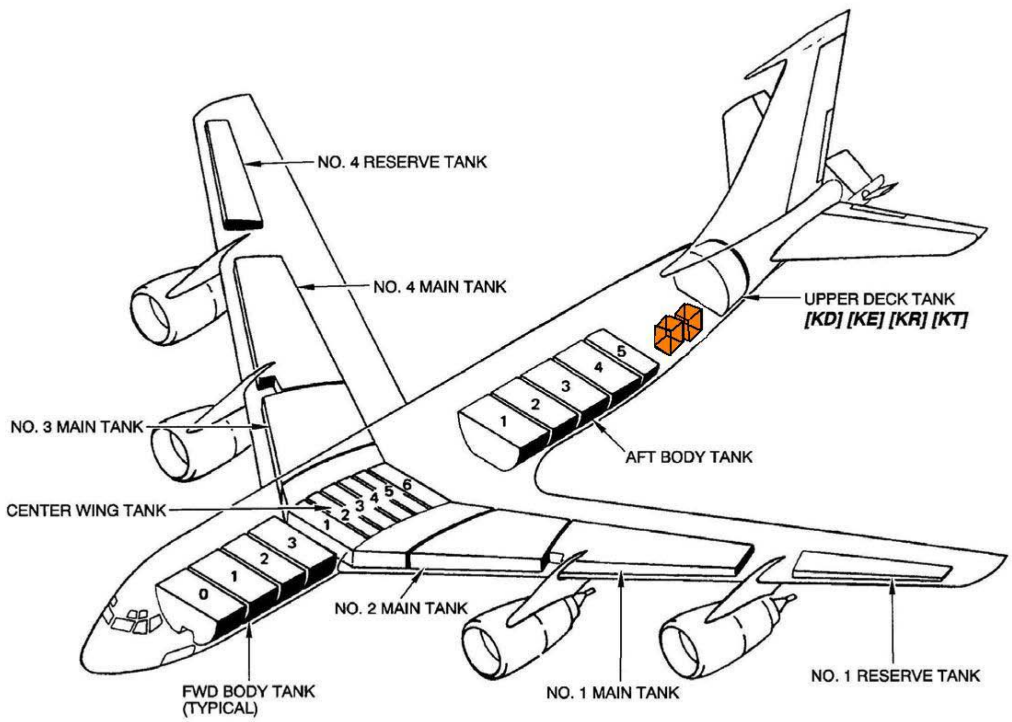
Figure 5. Location of Upper Deck Tank (Boeing, 2009)



Similarly the average moment of the APUs, which were added in 1956, is approximately 416 inches aft of the 35% MAC line at station 1287 (Boeing, 2009: 3-1 - 3-5). The APUs which weigh 920 lbs each were added as part of the aircraft's "arctic capability provisions". To counter act this weight of 1840 lbs with equal weight (on an equal opposite moment forward of the 35% MAC line) one would add ballast at approximately the furthest most position in the cargo compartment (station 455), which incidentally is slightly forward of the forward body tank average station (station 490.3). This accounts for approximately 2,000 lbs of fuel in the forward body tank to ballast out the APUs alone. Figure 6 shows the approximate location of the KC-135 dual APUs

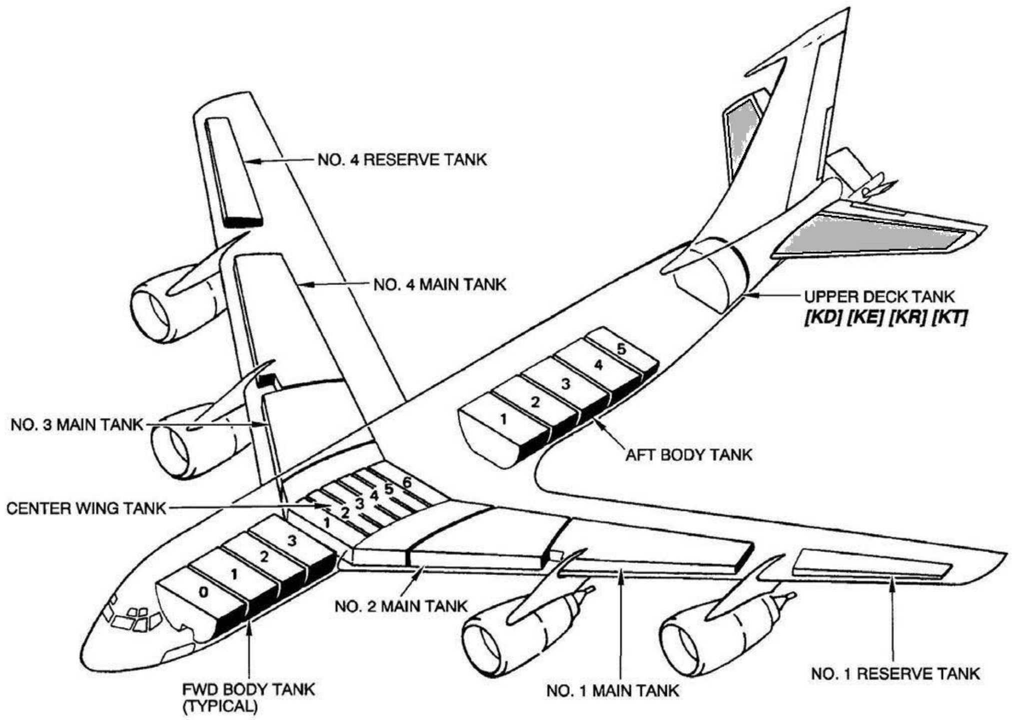
(shaded).

Figure 6. Location of APUs (Boeing, 2009)



Another modification that accompanied the reengining upgrades that converted KC-135A and Q models to KC-135E, R and T models was the addition of a larger horizontal stabilizer. The larger horizontal stabilizer much like the addition of the "tall tail" vertical stabilizer, gave the aircraft increased stability and authority required to handle her new and more powerful power plants. Like most of the other improvements the horizontal stabilizer came with an associated weight penalty of 160 lbs and a very long moment arm (station 1543) approximately 671 inches aft 35% MAC line. Figure 7 illustrates the larger horizontal stabilizers found on the KC-135E, R and T models with the smaller KC-135A model horizontal stabilizer represented by the shaded area.

Figure 7. Horizontal Stabilizer Growth (Boeing, 2009)



The last major modification made to the KC-135 fleet near the tail of the aircraft was the upgrade of the "standard speed boom" to the "high speed boom", this allowed for operations above 335 KIAS, but also added 83 lbs to the aft-most point on the aircraft (station 1676). Although the weight of many of these pieces of equipment may seem trivial the compounded effect of continually adding small components, especially to the aft of the aircraft has had a very large effect on its total weight and increasingly aft CG.

Most aircraft used for commercial purposes are ballasted by the manufacturer and remain within ballast trim for the duration of their service. This is because commercial requirements are fairly static and large refits of their fleet are not common. However, the

military often refits existing airframes to accomplish new mission sets. Reengineering often entails removal of equipment for old mission requirements and the addition of new equipment for the new mission requirements. This rarely results in a balanced airframe.

A historic example of reballasting a military aircraft for a new mission set is the development of the RF-86F. In 1952, the USAF Far East Material Command took three F-86F fighter aircraft and converted them into RF-86Fs by removing all armament, radars and gun sights, replacing them with a camera suite. The resultant aircraft was horribly unbalanced, so the decision was made to add "ballast totaling almost 750 lbs, needed to re-align the aircraft center of gravity…to the forward fuselage" (Davis, 1998). This is very similar to the changes that occurred in the KC-135, but instead of occurring all at once they were spread over more than five decades.

The KC-135 has had multiple changes made to its physical structure and its onboard equipment. Many of these changes have been small, but the cumulative effect has had an insidious detriment to its weight and CG. The culture that has developed around the KC-135, like many "legacy aircraft", has become tantamount to religion, making it difficult to question why things are done the way they have always been done. This is compounded by the fact that the original engineers who developed the aircraft have all long-since retired or in many cases died, which makes gaining access to the logic behind many of their actions speculative. By questioning the reality behind the procedures and thoroughly examining the evolution of the machine it is possible to develop better methods for doing business.

Chapter 3 discusses the methods used to evaluate the proposed solutions and the treatment of data that deliver the results found in Chapter 4.

III. Methodology

Instrument Development

This investigation employs a rudimentary weight and moment-arm construct. The KC-135 much like a see-saw has a balance point along each of its axes. This particular investigation is only concerned with the longitudinal axis and its management through weight application at counter-balance points to achieve equilibrium. The distance from the fulcrum to these counter-balance points is in direct inverse proportion to the weight required to achieve equilibrium. In short, the further from the balance point ballast weight is applied the less weight that is required to balance the aircraft longitudinally. The less weight used to ballast the airframe the lighter the total balanced aircraft weighs. Figure 2, an excerpt from T.O. 1C-135-5-1, shows the moment stations as they relate to the airframe longitudinal axis for reference.

Data and Constraints

The investigation of reballasting the KC-135 fleet, due to fleet size and variation, was subject to certain constraints and categorization to maintain a manageable focus. The weight and balance data used in this study supplied the weights for 439 KC-135s. Only USAF active aircraft tails were considered in this examination. This eliminated all Foreign Military Sales (FMS) KC-135s that are either owned or on long-term lease to foreign governments. Additionally, USAF owned aircraft that are in the bone yard, under mothball or retired status, and static display aircraft tails were not considered when they

could be identified. Only the active flying USAF KC-135 R-model and T-model aircraft were considered. This constraint is important not only for focus but also for relevance of the data since the U.S. government would not commit funds to reballast foreign aircraft nor aircraft that are not programmed to fly.

Even within this restricted community there are some variations that are examined individually due to substantial structural and/or mission differences. While all of these aircraft are equipped with CFM56-2 engines the primary difference between R-model and T-model aircraft is the capability of the KC-135T to partition different types of fuel within its tanks and most importantly the 850 lbs of installed ballast in the aircraft's nose. While T-model aircraft are structurally unique they are not currently used to fulfill a unique mission, although the capability remains for future mission expansion at present they are used interchangeable with their R-model sisters. Within the KC-135R model designation there are two subgroups, Multi-Point Refueling System (MPRS) tails and Air to Air Refuelable (AAR) tails. MPRS aircraft are unique because they are plumbed to allow for the attachment of "probe and drogue" refueling pod receptacles on each wing tip and AAR aircraft as the name suggests can be refueled in flight through boom refueling. Both MPRS and AAR tails are capable and tasked with expanded mission sets due to their capabilities, so both their physical differences with regard to weight and balance and their capabilities and missions are considered separately from the general population of KC-135R aircraft.

The weight and balance source data used to calculate ballast requirements in this investigation comes from the most recent aircraft depot weigh-in, accomplished post Program Depot Maintenance (PDM), for each individual aircraft as of the end of 2008.

This data was provided by the KC-135 Systems Group (SG) at the 550 ACSS where it is maintained. The KC-135 is currently undergoing an upgrade from Block 30 to Block 40, an avionics upgrade that provides Global Air Traffic Management (GATM) capability. This upgrade was discovered to have an appreciable effect on weight and CG (discussed later). All aircraft were weighed in basic configuration, all removable equipment was absent, and no fuel was present in the tanks.

Despite, the origin of the weight and balance data some validation was performed to ensure the highest level of accuracy possible. First the entire data set of 439 aircraft was compared side by side with the production list of KC-135 tails produced to reveal 3 known phantom tail numbers (clerical errors, such as typos or the wrong year associated with last 4 digits of tail number resulting in a double entry). Following the validation of the aircrafts' existence all known FMS aircraft that the SG data base had weight and balance data on were eliminated. This left 421 aircraft 367 KC-135Rs (including 20 MPRS and 7 AAR) and 54 KC-135Ts. Unfortunately, the number of KC-135s in the fleet is known to have some minor inaccuracies. The actively commissioned fleet of USAF KC-135s is officially 419 aircraft (417 used as tankers to include 54 T-models, 20 MPRS and 8 AAR tails; and two special use KC-135Rs the "Ice Tanker" test bed 61-0320 and the "Speckled Trout" aircraft 63-7980 used for transporting the CSAF) as of February 15, 2010 (Mott, 2010). While the T-model and MPRS aircraft are all accounted for, the SG was missing the weight and balance for one AAR aircraft. In addition to having one less AAR aircraft in our records there are 3 additional KC-135R (non-MPRS and non-AAR) aircraft in the database. These aircraft were discovered after data analysis to have recently attrited from the fleet (63-8886, 57-1470 and 57-1418, they all appear in

the KC-135R Block 30 fleet segment) (Mott, 2010). Despite, the inclusion of these three recently destroyed aircraft (none of which were unusual in their weight and balance characteristics) and the absence of the one AAR tail the data presented can be treated with a high level of confidence. For the purposes of this study the USAF KC-135 fleet population is treated as 421 aircraft.

The final step in preparing the weight and balance data was to use the GATM schedule to validate the date all Block 40 aircraft were upgraded from Block 30 configuration. The weigh dates from the weight and balance data base were then cross-referenced with the upgrade dates to determine at the time of weighing if each individual tail was in Block 30 or Block 40 configuration. The knowledge of the individual aircraft's configuration at time of weighing is of vital importance since T.C.T.O. 1C-135-1547 (Block 30 to Block 40 conversion) removes 2,105 lbs of equipment with an average moment of $758.44 * 10^3$ inch pounds and adds 3,221.9 lbs of equipment with an average moment of $1,226.82 * 10^3$ inch pounds, resulting in a net weight gain of 1,116.9 lbs and a moment of $468.48 * 10^3$ inch pounds (Amaya, 2009). This moves the aircraft CG forward because the enhance avionics suite acts as equipment ballast.

The calculation of weight and balance for this investigation builds upon the basic weight and balance provided by the KC-135 SG. Fuel weight and moment were added to model minimum fuel, as determined by Boeing EA 08-043-135AMC, which prevents boost pump cavitation during normal operation in each of the main tanks. The specific amounts prescribed by EA 08-043-135AMC were 513 lbs indicated for main tanks 1 and 4 and 502 lbs for main tanks 2 and 3. These quantities where calculated to account for potential fuel probe error, but due to display limitations the crew can only read quantities

in 100 lb increments. Policy change levied by AMC GM 1 to 11-2-KC-135 Vol. 3 dictated 600 lbs per main tank to account for this fuel panel fidelity issue.   The ballast fuel of 3,500 lbs in the forward body tank, prescribed by EA 08-043-135AMC (Data Revision) was replaced in this analysis with the “required minimum ballast” to maintain a CG forward of 35% MAC, the aft CG limit per T.O.1C-135-1-1.

EA 08-043-135AMC was initially released to the Air Force to include the weight and balance data points for the entire KC-135R/T fleet, to include FMS aircraft. Many FMS aircraft have additional equipment not found on USAF aircraft. The control aircraft for EA 08-043-135AMC was a KC-135R that belongs to the Singapore Air Force. EA 08-043-135AMC (Data Revision) was a rework of the initial data that excluded FMS aircraft. The controlling aircraft with the largest ballast requirement for this revised data (57-1462) required 3,410 lbs of fuel to maintain a CG forward of 35% MAC. The method used for determining this amount during EA 08-043-135AMC (Data Revision) varies slightly from the method used in this investigation. EA 08-043-135AMC (Data Revision) placed the entire crew at the aft most position within the plane (station 1300), while this study did not calculate crew weight at that position. While it is arguably more conservative to apply the 3 person crew’s weight at the least advantageous position it is both unrealistic and overly conservative since actual tip-back doesn’t occur until 41.67% MAC on the ground (Boeing Aero, 2009) and all 3 crew members would never be at station 1300 in flight.

GM 1 to 11-2-KC-135 Vol. 3 rounded the fuel quantity required for ballast in the forward tank up to 3,500 lbs to account for fuel panel fidelity issues. “Required minimum ballast” for the purpose of this examination is determined based on the

individual treatment conducted and its individual constraints. Table 3 lists the types of treatments applied to the Fleet Segments listed in Table 4.

Table 3. Treatments

Treatment A.	Use "fuel ballast" to maintain CG limits
Treatment B.	Use "equipment ballast" supplemented by "trim ballast" to maintain CG limits
Treatment C.	Use "weight ballast" to maintain CG limits

The data analysis was conducted by first ballasting every aircraft in the fleet individually for each treatment. Then fuel cost mitigation analysis was determined with regard to average weight reduction across various segments of the fleet. This use of average should not be confused with a blanket prescription. Averages serve effectively to model weight and cost savings in the absence of aircraft tail number specific programmed flying hours. While data of this specificity may be available for very small fleets the USAF flying hours are programmed primarily at the fleet level. The CoW fuel determined to calculate pollution/GHG mitigation were based on aggregate fleet flying hours multiplied by the product of delta (Δ) weight average (for the particular fleet segment and treatment) and the KC-135 CoW. This approach does not account for differences in flying hours from one aircraft to another and it was recognized as a limitation of the data available. Active fleet management; however, does aggressively target rotation of aircraft tails to balance out airframe hours which minimizes this assumption's variability, especially over the remaining 30 plus years of aircraft life expectancy (Air Mobility Command, 2008).

Table 4. Fleet Segments

	Block 30	Block 40	Simulated Block 40
KC-135R (non-MPRS and non-AAR)	Fleet Segment I.	Fleet Segment II.	Fleet Segment III.
KC-135R (MPRS)	Fleet Segment IV.	Fleet Segment V.	Fleet Segment VI.
KC-135R (AAR)	Fleet Segment VII.	Fleet Segment VIII.	Fleet Segment IX.
KC-135T	Fleet Segment X.	Fleet Segment XI.	Fleet Segment XII.

Each of the fleet segments was individually subjected to the various treatments (Treatment A, B and C), as they were appropriate for examination. Simulated Block 40 aircraft (Block 30 aircraft with weight and moment prescribed by GATM upgrade T.C.T.O. to simulate upgrade to Block 40) segments were principally used to validate that Block 40 segment findings would not be invalidated by subsequent Block upgrade of Block 30 aircraft as they joined the Block 40 segments. Since this segment was added, decisions made specific to Block 40 aircraft will remain valid across the entire expanding population, despite airframe upgrades.

This investigation encompasses the entire USAF KC-135 fleet and is not simply a statistical representation. Solutions found will account for every aircraft in the fleet and the raw data can be used prescriptively to fix the weight and balance issues of every USAF KC-135 by individual tail number.

Instrument Administration

The approach used in this investigation to determine ballast requirements was based on aircraft individual requirements not fleet-wide blanket solutions. Currently the use of 3,500 lbs of fuel in the forward body fuel tank, as ballast, is a fleet-wide solution. This solution was developed to account for the worst case scenario, specifically aircraft 57-1462, as determined by EA 08-043-135AMC (Data Revision). The use of fuel for ballast does not lend itself to tailored solutions since tailored guidance for fuel carriage would need to specify individual aircraft tails. Policy that specific can easily lead to confusion for aircrew and ground crew members, who change from one aircraft to the next on a routine basis. It is for this reason that aircraft 57-1462's weight and ballast situation, as the controlling aircraft, dictates the carriage of 3,500 lbs of ballast fuel by aircraft 59-1509 despite the fact that it's CG (at basic weight) is 35.8% MAC as opposed to 57-1462's CG which is 38.4% MAC (at basic weight). The fuel load of 500 lbs in the forward body tank would be sufficient to ballast aircraft 59-1509, but because of the one-size-fits-all approach inherent to fuel ballast, that aircraft carries an additional 3,000 lbs of "dead weight." The unique advantage to deliberate ballast, accomplished with weight ballast or equipment and trim ballast, is it can be done on an individual aircraft basis and eliminates this type of excess.

In this investigation, the application of weight ballast was systematically managed to maximize moment-arm advantage. Except for ballast with mission enhancement value (deemed to override a less advantageous moment-arm advantage) all ballast was applied at the station with the longest mechanical advantage possible (station 178 in the case of weight ballast), in the smallest amount necessary to obtain a CG of 35% MAC or less. The discrete nature of equipment ballast does not lend itself to "trimming out" the ballast

to an exact value; however, since the forward CG limit for the KC-135 is 18% MAC and armor ballast did not put any aircraft in a CG regime anywhere close to that during the analysis treatments, it is safe to say CG of 35% MAC or less is a satisfactory result.

Specifically, the fleet was examined within the Excel© based, *KC-135 weight and balance calculator*, developed for this study. The properties to be examined for each treatment were inputted by attributing the appropriate weight at the appropriate station location (represented by a specific column in the spreadsheet). In the example below illustrated in Figure 8, cockpit armor is applied by placing 850 lbs in the column titled *Station 269 Armor*; this automatically generates a moment arm for that equipment in the column directly to the right. In this calculator, fuel is represented the same way as equipment ballast and weight ballast, as a weight applied at an appropriate average station. Figure 8 demonstrates how minimum main tank fuel is inputted as 1200 lbs in both the column titled *1/4 Main Station 890.9* and the column titled *2/3 Main Station 796.2*, because tanks 1 and 4 are symmetrical along the longitudinal axis and share an average station location the 600 lbs of fuel for each tank is combined and applied once as 1200 lbs, the same is true for tanks 2 and 4. Each row represents a specific aircraft by tail number.

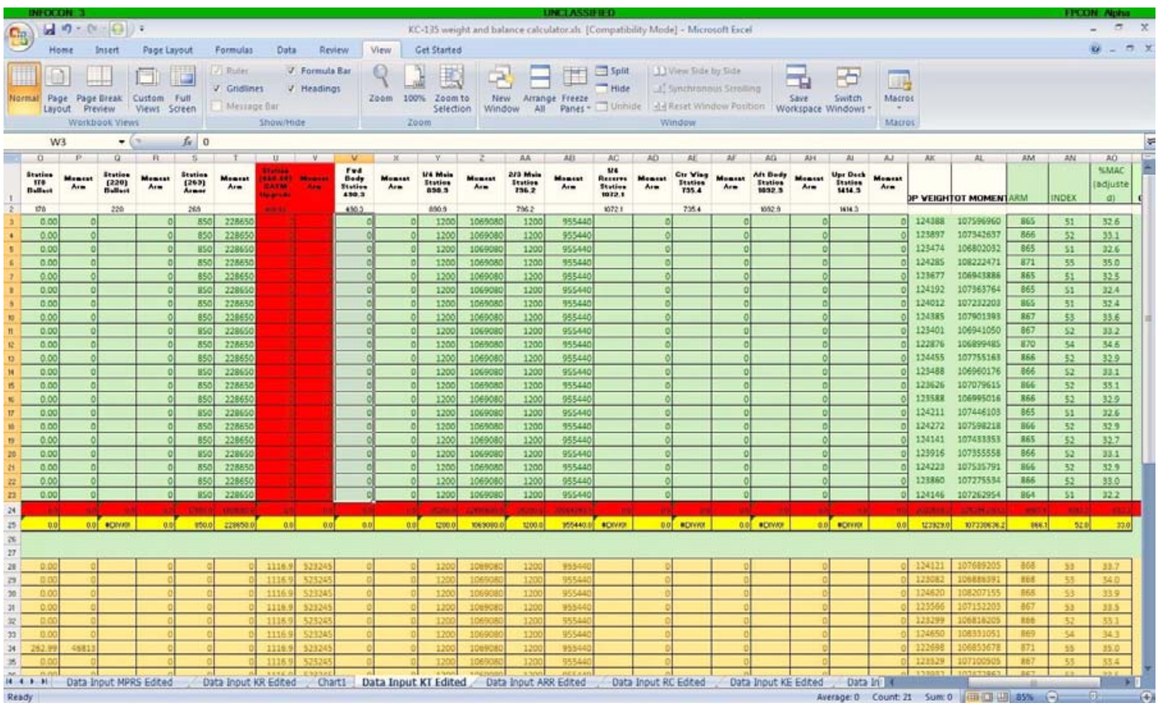
Figure 8. Blow up of KC-135 Weight and Balance Calculator

Station 178 Ballast	Moment Arm	Station (220) Ballast	Moment Arm	Station (269) Armor	Moment Arm	Station (468.48) GATM Upgrade	Moment Arm	Fwd Body Station 490.3	Moment Arm	1/4 Main Station 890.9	Moment Arm	2/3 Main Station 796.2	Moment Arm
178		220		269		468.48		490.3		890.9		796.2	
0.00	0		0	850	228650	0	0	0	0	1200	1069080	1200	955440
0.00	0		0	850	228650	0	0	0	0	1200	1069080	1200	955440
0.00	0		0	850	228650	0	0	0	0	1200	1069080	1200	955440
0.00	0		0	850	228650	0	0	0	0	1200	1069080	1200	955440

0.00	0		0	850	228650	0	0	0	0	1200	1069080	1200	955440
0.00	0		0	850	228650	0	0	0	0	1200	1069080	1200	955440
0.00	0		0	850	228650	0	0	0	0	1200	1069080	1200	955440
0.00	0		0	850	228650	0	0	0	0	1200	1069080	1200	955440

Figure 9 is a screen shot taken of the KC-135T model Block 40 aircraft (fleet segment XI) during a cockpit armor and minimum main tank fuel treatment. The individual aircraft operational weights can be seen in column “AK” and the CGs can be seen in column “AO”.

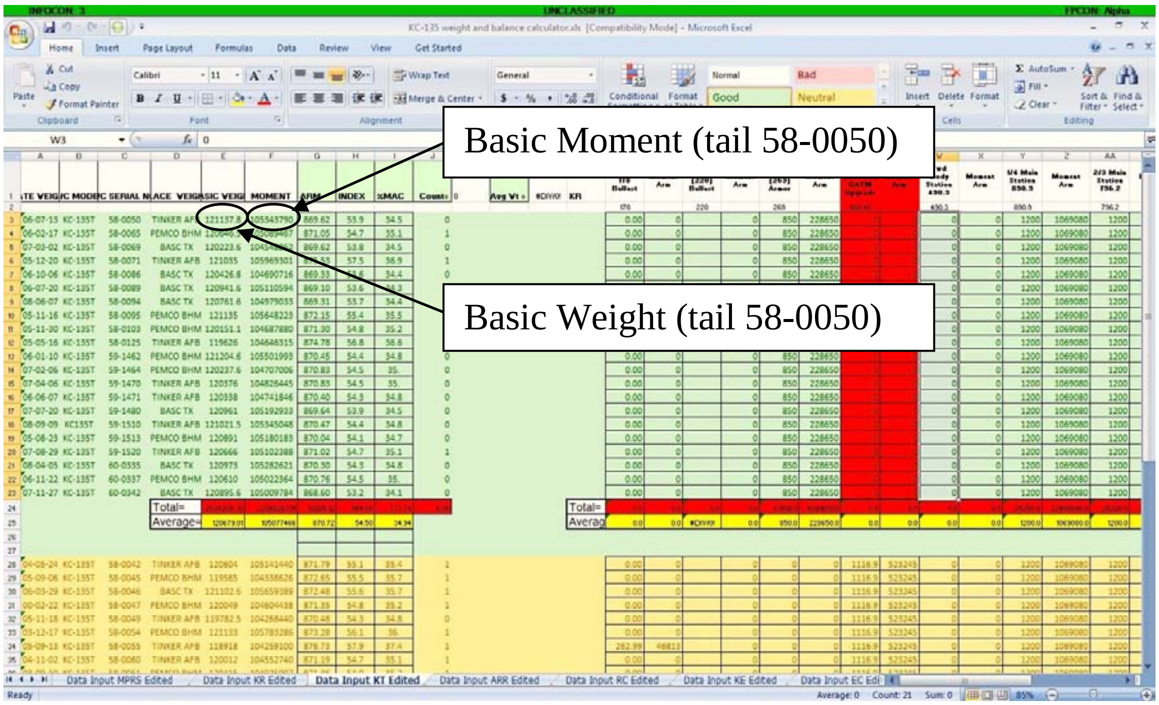
Figure 9. Screen Shot of KC-135 Weight and Balance Calculator



The *KC-135 weight and balance calculator* works by converting the weights applied in the appropriate columns into moments (in the columns directly to the right of each weight column) then summing the individual moments and adding them to the basic moment for that particular aircraft (see Figure 10. Weight and Moment Columns Screen Shot). In Figure 10, the data in column “A” through column “I” is data supplied by the

SG, all columns past column “I” were developed to calculate the result of applying weight on top of the basic airframe.

Figure 10. Weight and Moment Columns Screen Shot



The calculation of “weight ballast” required at station 178 was calculated by first simulating the other constraints (main tank fuel, forward body fuel, cockpit armor, etc.), then using Solver© to populate the ballast weight required for each individual aircraft tail at station 178 (by placing the appropriate weight in column “O”). Solver© is used to examine weight ballast required for the MPRS Block 40 (fleet segment V) during the treatment B data collection (Figure 11). The target cell in Solver© is “O13” (the column total for Block 40 weight at station 178), and Solver© is instructed to minimize the value in that cell (this minimizes total weight used). Solver© is authorized to manipulate the weight placed in cells “O3” through “O12” (representing individual aircraft ballast needed) to accomplish its objective, given the constraint that all the values in cells “AO3”

through “AO12” (the CG in % MAC) are less than or equal to 35.

Figure 11. Solver Screen Shot

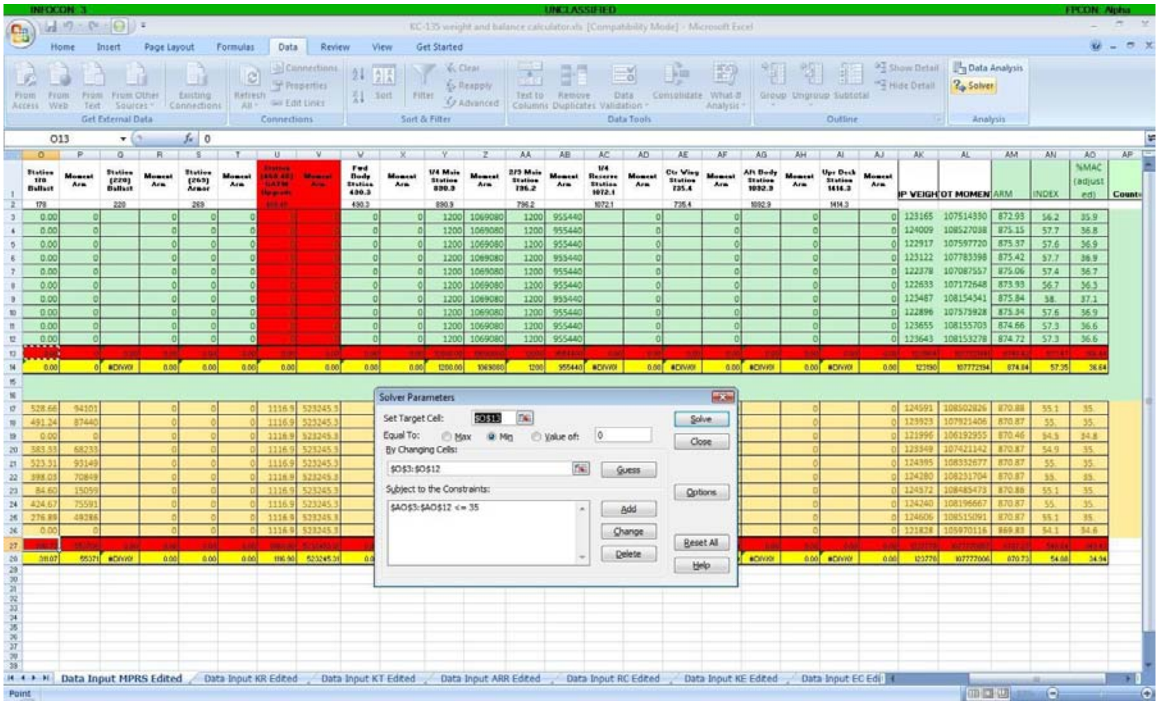
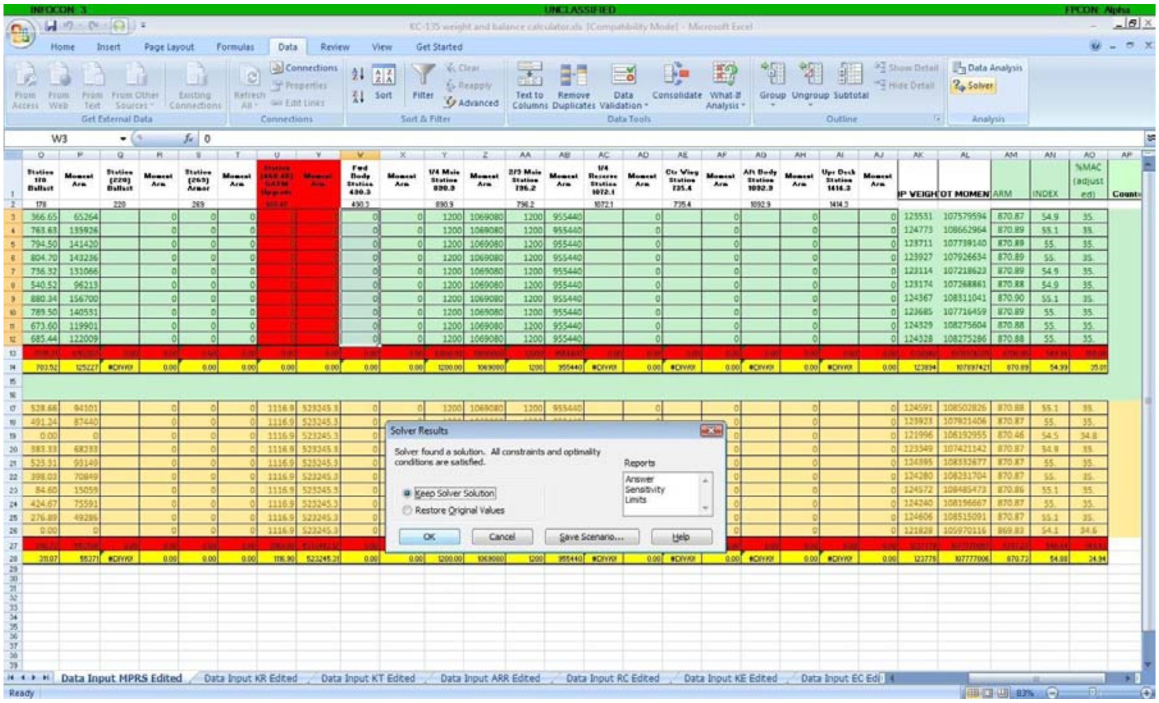


Figure 12 shows the results after Solver© has been run for the scenario in Figure 11. The values in column “O” are the specific weights required to ballast each individual aircraft (using station 178) given the specific treatment of this fleet segment. Column “AO” in Figure 12 shows how the weights applied in column “O” created ballasted aircraft with respective CGs of 35% MAC or less.

Once the individual treatments were run for each fleet segment, descriptive statistics were gathered for aircraft CG (column “AO”), aircraft operating weight (column “AK”), and finally ballast weight applied at station 178 (column “O”) when applicable. It is this data organized by fleet segment and treatment that populates the tables in this report.

Figure 12. Solver “Solved” Screen Shot



The calculation of both fuel mitigation, reported in pounds of JP-8, and fuel cost mitigation, reported in U.S. 2010 dollars, was determined by comparing “zero fuel” weights of the ballasted airframes with the current configuration “zero fuel” weight (directed by GM 1 to 11-2-KC-135 Vol. 3). The average difference in aircraft weight by fleet segment was then combined (using a weighted average due to difference in fleet segment sizes) to determine an average weight difference per aircraft across the entire fleet. This average weight difference was multiplied by the CoW for the KC-135 to determine average fuel mitigation in pounds of JP-8 per hour. The average fuel mitigation in pounds per hour was multiplied across the annual KC-135 flying hours to determine annual fleet fuel mitigation. Fuel cost mitigation was calculated by multiplying annual fleet fuel mitigation by the cost of fuel. The cost of aircraft

modifications prescribed was totaled for each solution set and divided by the annual fuel cost mitigation to determine a recoupment horizon for each solution set.

IV. Results and Analysis

Empty Aircraft

Analysis of the KC-135 fleet without fuel on board or any form of ballast is given in Table 5 and Table 6.

Table 5. Empty Aircraft Block 30

	R-Model		T-Model		MPRS		ARR	
Block 30								
CG	Mean	37.5710967	Mean	35.541147	Mean	37.456899	Mean	36.40134
CG	Minimum	35.9308172	Minimum	34.708476	Minimum	36.360758	Minimum	35.97779
CG	Maximum	38.5391706	Maximum	37.424979	Maximum	38.026555	Maximum	36.93265
CG	AC w/CG >35.0	285	AC w/CG >35.0	30	AC w/CG >35.0	10	AC w/CG >35.0	5
Weight	Mean	119106.295	Mean	120048.38	Mean	119949.96	Mean	120572.9
Weight	Minimum	116840	Minimum	118918	Minimum	118311	Minimum	120047
Weight	Maximum	122501	Maximum	121133	Maximum	120970.6	Maximum	120934
Weight	Count	285	Count	33	Count	10	Count	5

Table 6. Empty Aircraft Block 40

	R-Model		T-Model		MPRS		ARR	
Block 40								
CG	Mean	36.9440527	Mean	34.94009	Mean	36.901044	Mean	36.03344
CG	Minimum	35.847272	Minimum	34.063204	Minimum	36.095907	Minimum	35.88955
CG	Maximum	37.8598048	Maximum	36.926869	Maximum	37.319457	Maximum	36.17733
CG	AC w/CG >35.0	55	AC w/CG >35.0	6	AC w/CG >35.0	10	AC w/CG >35.0	2
Weight	Mean	119739.969	Mean	120679.01	Mean	120790.43	Mean	121608.3
Weight	Minimum	118316	Minimum	119626	Minimum	119978	Minimum	121244.5
Weight	Maximum	120855	Maximum	121204.6	Maximum	121609	Maximum	121972
Weight	Count	55	Count	21	Count	10	Count	2

Quick comparison of the mean CGs (reported as % MAC) demonstrates some basic traits of the fleet segments with regard to weight and balance. The T-model KC-135s are not surprisingly the best ballasted aircraft in the fleet, demonstrated by the lowest % MAC value among the Block 30 aircraft (fleet segment X) and among the Block 40 aircraft (fleet segment XI). This is logical due to the ballast of 850 lbs added to station 178 to these aircraft in the 1960s. The MPRS and KC-135R (non-MPRS and non-AAR) aircraft have very similar CGs both among Block 30 (fleet segments IV and I) and Block 40 aircraft (fleet segments V and II). The AAR aircraft have an average CG less than the other KC-135R models (MPRS and non-MPPRS), but they are not ballasted quite as well as the KC-135T aircraft. The better average ballast of the AAR aircraft (compared to the other R-models) was expected, due to the equipment and plumbing on these aircraft over the cockpit for receiver air-to-air refueling, which provides them with some forward equipment ballast.

When each category (KC-135R, KC-135T, MPRS and AAR) compares its Block 30 component to its Block 40 component the Block 40 aircraft are always better ballasted. This stands to reason because of the known addition of forward ballast to these aircraft during the upgrade process.

Quick analysis of the aircraft weight produces some similarly expected results. The weight difference between KC-135R (non-MPRS and Non-AAR) and KC-135T aircraft is approx 940 lbs (found in comparison both among Block 30 and Block 40 aircraft). This is logical because as stated earlier the T-model aircraft have 850 lbs of ballast already, the additional 90 lb difference can be explained by additional valves and equipment required to partition body fuel in the T-models. The MPRS aircraft proved to

be consistently heavier than the KC-135R (non-MPRS and non-AAR) aircraft, by an average of approximately 840 lbs for the Block 30 and approximately 1,050 lbs for the Block 40 aircraft. The greater weight of the MPRS aircraft is explained by an additional fuel manifold that runs the length of the wings that supplies the MPRS pods (the difference between Block 30 (fleet segment IV) and Block 40 (fleet segment V) appears to be due to a small MPRS aircraft population; only 10, Block 30 and 10, Block 40, giving greater statistical authority to individual aircraft anomalies in weight). The additional fuel manifold present on the MPRS aircraft is located in the forward portion of the aircraft's wing which appears to minimize its effect on CG in these aircraft. The heaviest aircraft by fleet segment are the AAR airframes (fleet segments VII and VIII) weighing between 500 and 1,000lbs more than either the T-model (fleet segments X and XI) or MPPRS aircraft (fleet segments IV and V).

The differences within each category between Block 30 and Block 40 aircraft average weights were somewhat surprising considering the knowledge of the exact equipment weight change as described by the modification instructions (1,116.9 lbs). The weight difference within both the KC-135R (fleet segments I and II) and KC-135T (fleet segments X and XI) categories were only about 630 lbs, significantly less than the expected 1,116.9 lbs, despite a fairly large population of KC-135R Block 40 aircraft (55 total in fleet segment II). The differences among the MPRS (fleet segments IV and V) and AAR (fleet segments VII and VIII) categories were also slightly smaller than expected but closer to the 1,116.9 lb mark (MPRS 840 lb difference and AAR 1,035 lb difference). Explanation of this smaller than expected weight change is purely speculative; however, it may be possible that Block 40 upgrade schedule indirectly

favored lighter aircraft. The selection of aircraft by production year could potentially do this if substitute materials with slightly different weights where used during the long production cycle. Regardless of the observed variation, the validity of the weight and balance information for T.C.T.O. 1C-135-1547 provided by the KC-135 Weight and Balance Authority Office is maintained throughout this study, because this observed data is subject to numerous variables.

Aircraft (No Ballast) with Minimum Fuel (600 lbs in main tanks 1-4)

The minimum main tank fuel option applied across the entire fleet yielded the following results by fleet segment. Table 7 shows the results for Block 30 aircraft, Table 8 shows the Block 40 aircraft results and Table 9 shows the results for all Block 30 aircraft simulating conversion to Block 40 (using weight and balance correction). It is important to note that "minimum fuel" refers to fuel required to run the engines and is a component of "zero fuel", but not necessarily the same. In the case of fuel ballast used in treatment A zero fuel is the compilation of minimum fuel and fuel ballast.

Table 7. Minimum Fuel Block 30

	R-Model		T-Model		MPRS		ARR	
Block 30								
CG	Mean	37.297271	Mean	35.309211	Mean	37.187242	Mean	36.15362
CG	Minimum	35.6848056	Minimum	34.492381	Minimum	36.109197	Minimum	35.73845
CG	Maximum	38.2541892	Maximum	37.153623	Maximum	37.747047	Maximum	36.67497
CG	AC w/CG >35.0	285	AC w/CG >35.0	27	AC w/CG >35.0	10	AC w/CG >35.0	5
Weight	Mean	121506.295	Mean	122448.38	Mean	122349.96	Mean	122972.9
Weight	Minimum	119240	Minimum	121318	Minimum	120711	Minimum	122447
Weight	Maximum	124901	Maximum	123533	Maximum	123370.6	Maximum	123334
Weight	Count	285	Count	33	Count	10	Count	5

Table 8. Minimum Fuel Block 40

	R-Model		T-Model		MPRS		ARR	
Block 40								
CG	Mean	36.6839701	Mean	34.721057	Mean	36.644019	Mean	35.79491
CG	Minimum	35.6059294	Minimum	33.861638	Minimum	35.854518	Minimum	35.6531
CG	Maximum	37.5825523	Maximum	36.669851	Maximum	37.054918	Maximum	35.93672
CG	AC w/CG >35.0	55	AC w/CG >35.0	3	AC w/CG >35.0	10	AC w/CG >35.0	2
Weight	Mean	122139.969	Mean	123079.01	Mean	123190.43	Mean	124008.3
Weight	Minimum	120716	Minimum	122026	Minimum	122378	Minimum	123644.5
Weight	Maximum	123255	Maximum	123604.6	Maximum	124009	Maximum	124372
Weight	Count	55	Count	21	Count	10	Count	2

Table 9. Minimum Fuel Block 30 Converted

	R-Model		T-Model		MPRS		ARR	
Block 30 converted								
CG	Mean	35.761186	Mean	33.802816	Mean	35.662632	Mean	34.64602
CG	Minimum	34.1347994	Minimum	32.990038	Minimum	34.574015	Minimum	34.23532
CG	Maximum	36.7510401	Maximum	35.616525	Maximum	36.224764	Maximum	35.16509
CG	AC w/CG >35.0	275	AC w/CG >35.0	1	AC w/CG >35.0	8	AC w/CG >35.0	2
Weight	Mean	122623.195	Mean	123565.28	Mean	123466.86	Mean	124089.8
Weight	Minimum	120356.9	Minimum	122434.9	Minimum	121827.9	Minimum	123563.9
Weight	Maximum	126017.9	Maximum	124649.9	Maximum	124487.5	Maximum	124450.9
Weight	Count	285	Count	33	Count	10	Count	5

The change in CG from an empty aircraft to an aircraft carrying the minimum fuel load of 600 lbs in each of the main tanks is a consistent shift forward of approximately .25% MAC, within all fleet segments. The minimum main tank fuel (600 lbs in main tanks 1-4) is used as the base line for comparison throughout the remainder of this study since there is no operational situation that would result in anything less. The comparison

between empty and minimum fuel is used to illustrate the minimal (but worth considering) shift in CG that occurs in a relatively uniform manner across the fleet. It is a consideration, for those rare maintenance situations (outside depot maintenance) that require all fuel be drained, that a small additional ballast weight may need to be applied for the duration of the maintenance operation, but the enormous “pet rocks” (2 ton pieces of concrete placed in the forward section of the cargo bay) currently employed during depot maintenance would no longer be required to replace the 3,500 lbs of ballast fuel assuming treatment B or C is used.

The inclusion of Table 9 which depicts Block 30 aircraft converted to Block 40 is to help demonstrate how policy directed at Block 40 aircraft can be validated before complete conversion has occurred within the fleet. This table serves a base-line within the study for comparison with equipment and weight ballast tables for individual fleet segments.

Aircraft with Minimum Main Tank Fuel & Cockpit Armor (No Trim Ballast)

Aircraft examined by fleet segment with minimum fuel in the main tanks (600 lbs in main tanks 1-4) and 850 lbs of armor (the weight of 110 sq ft of LAST© armor, such as that previously tested on the KC-135 airframe) applied at the determined average station of 269, garnered the following results. Table 10 shows the results for Block 30 aircraft, Table 11 shows the Block 40 aircraft results and Table 12 shows the results for all Block 30 aircraft simulating conversion to Block 40.

Table 10. Armor Analysis without Trim Ballast Block 30

	R-Model		T-Model		MPRS		ARR	
Block 30								
CG	Mean	35.5528212	Mean	33.591807	Mean	35.455471	Mean	34.43773
CG	Minimum	33.9188939	Minimum	32.776795	Minimum	34.361686	Minimum	34.02624
CG	Maximum	36.550407	Maximum	35.407529	Maximum	36.019826	Maximum	34.95824
CG	AC w/CG >35.0	265	AC w/CG >35.0	1	AC w/CG >35.0	7	AC w/CG >35.0	0
Weight	Mean	122356.295	Mean	123298.38	Mean	123199.96	Mean	123822.9
Weight	Minimum	120090	Minimum	122168	Minimum	121561	Minimum	123297
Weight	Maximum	125751	Maximum	124383	Maximum	124220.6	Maximum	124184
Weight	Count	285	Count	33	Count	10	Count	5

Table 11. Armor Analysis without Trim Ballast Block 40

	R-Model		T-Model		MPRS		ARR	
Block 40								
CG	Mean	34.9527619	Mean	33.016437	Mean	34.92775	Mean	34.09567
CG	Minimum	33.8620101	Minimum	32.165898	Minimum	34.143327	Minimum	33.94988
CG	Maximum	35.8502624	Maximum	34.956808	Maximum	35.339958	Maximum	34.24147
CG	AC w/CG >35.0	22	AC w/CG >35.0	0	AC w/CG >35.0	5	AC w/CG >35.0	0
Weight	Mean	122989.969	Mean	123929.01	Mean	124040.43	Mean	124858.3
Weight	Minimum	121566	Minimum	122876	Minimum	123228	Minimum	124494.5
Weight	Maximum	124105	Maximum	124454.6	Maximum	124859	Maximum	125222
Weight	Count	55	Count	21	Count	10	Count	2

Table 12. Armor Analysis without Trim Ballast Block 30 Converted

	R-Model		T-Model		MPRS		ARR	
Block 30 converted								
CG	Mean	34.0430919	Mean	32.111122	Mean	33.956847	Mean	32.95572
CG	Minimum	32.3960301	Minimum	31.300175	Minimum	32.853052	Minimum	32.54864
CG	Maximum	35.0723283	Maximum	33.896847	Maximum	34.523347	Maximum	33.47394
CG	AC w/CG >35.0	1	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	123473.195	Mean	124415.28	Mean	124316.86	Mean	124939.8
Weight	Minimum	121206.9	Minimum	123284.9	Minimum	122677.9	Minimum	124413.9
Weight	Maximum	126867.9	Maximum	125499.9	Maximum	125337.5	Maximum	125300.9
Weight	Count	285	Count	33	Count	10	Count	5

Table 10, Table 11 and Table 12 clearly depict a significant forward shift in aircraft CG when cockpit armor is added. Cockpit armor moves CG forward by more than 1.7% MAC among the Block 30 aircraft, across all fleet categories (R-model fleet segment I, T-model fleet segment X, MPRS fleet segment IV and ARR fleet segment VII). Significantly, even among Block 30 aircraft this pushes the average CG for T-model (fleet segment X) and ARR aircraft (fleet segment VII) forward of the critical 35% MAC and even brings the R-model (fleet segment I) and MPRS (fleet segment IV) categories average CGs very close to that mark.

The Block 40 aircraft, which also experience a forward shift in CG of 1.7% or more from the addition of cockpit armor, saw the average CG in all categories move ahead of the crucial 35% MAC threshold. Table 12 demonstrates that like the Block 40 aircraft, the remaining Block 30 aircraft when converted to Block 40 will experience similar results that will bring the average CGs in all categories forward of the 35% MAC mark.

Although average CGs are very good at describing trends within the fleet, it is critical that each individual aircraft meet the requirements for safe flight. Table 13 shows exactly how many aircraft would still have CGs of greater than 35% MAC, with minimum main tank fuel and cockpit armor only.

Table 13. Aircraft when Equipped with Armor Requiring Trim Ballast

	R-Model		T-Model		MPRS		ARR		Total w/CG>35
Block 30	AC w/CG >35.0	265	AC w/CG >35.0	1	AC w/CG >35.0	7	AC w/CG >35.0	0	273
Block 40	AC w/CG >35.0	22	AC w/CG >35.0	0	AC w/CG >35.0	5	AC w/CG >35.0	0	27
Block 30 converted	AC w/CG >35.0	1	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	1

When the totals for each category are added up, 273 of the 333 aircraft in Block 30 configuration would require some sort of additional ballast to reach the 35% MAC requirement. If one was to consider all aircraft were in Block 40 configuration (both those presently converted and those currently in Block 30 configuration) 28 of the 421 aircraft in the fleet would require additional ballasting given cockpit armor and minimum main tank fuel. This was significant because this laid the ground work for cost calculations done later in the study.

Aircraft with Minimum Main Tank Fuel & Minimum Weight Ballast (No Armor)

Aircraft examined by fleet segment subject to Treatment C with minimum fuel in the main tanks (600 lbs in main tanks 1-4) and minimum required weight ballast applied at station 178 (under the radome) to achieve a CG of 35% MAC or less without cockpit armor, garnered the following results. Table 14 shows the results for Block 30 aircraft; Table 15 shows the Block 40 aircraft results and Table 16 shows the results for all Block 30 aircraft simulating conversion to Block 40.

Table 14. Treatment C Block 30

	R-Model		T-Model		MPRS		ARR	
Block 30								
CG	Mean	34.9999864	Mean	34.961868	Mean	35.0	Mean	35.0
CG	Minimum	34.99508	Minimum	34.492381	Minimum	35.0	Minimum	35.0
CG	Maximum	35.0	Maximum	35.0	Maximum	35.0	Maximum	35.0
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	122480.912	Mean	122596.8	Mean	123278.54	Mean	123466.7
Weight	Minimum	119526.792	Minimum	121500.47	Minimum	121177.04	Minimum	122821.5
Weight	Maximum	126315.337	Maximum	123860.96	Maximum	124131.77	Maximum	124029.4
Ballast Weight	Mean	974.616875	Mean	148.41831	Mean	928.58334	Mean	493.7514
Ballast Weight	Minimum	286.7916	Minimum	0	Minimum	466.04049	Minimum	316.6394
Ballast Weight	Maximum	1414.33688	Maximum	912.18159	Maximum	1168.8853	Maximum	716.6742
Ballast Weight	Count	285	Count	33	Count	10	Count	5
Ballast Weight	AC req ballast	285	AC req ballast	27	AC req ballast	10	AC req ballast	5

Table 15. Treatment C Block 40

	R-Model		T-Model		MPRS		ARR	
Block 40								
CG	Mean	34.9966408	Mean	34.562938	Mean	35.0	Mean	35.0
CG	Minimum	34.9952447	Minimum	33.861638	Minimum	35.0	Minimum	35.0
CG	Maximum	35.0	Maximum	35.0	Maximum	35.0	Maximum	35.0
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	122859.548	Mean	123146.84	Mean	123893.95	Mean	124351.9
Weight	Minimum	120972.944	Minimum	122551.1	Minimum	123114.32	Minimum	123926
Weight	Maximum	123917.486	Maximum	124150.51	Maximum	124772.63	Maximum	124777.7
Ballast Weight	Mean	719.578595	Mean	67.826258	Mean	703.52104	Mean	343.6284
Ballast Weight	Minimum	256.94441	Minimum	0	Minimum	366.65113	Minimum	281.5162
Ballast Weight	Maximum	1103.60107	Maximum	715.50723	Maximum	880.33874	Maximum	405.7406
Ballast Weight	Count	55	Count	21	Count	10	Count	2
Ballast Weight	AC req ballast	55	AC req ballast	3	AC req ballast	10	AC req ballast	2

Table 16. Treatment C Block 30 Converted

	R-Model		T-Model		MPRS		ARR	
Block 30 converted								
CG	Mean	34.9855964	Mean	33.784172	Mean	34.942764	Mean	34.58993
CG	Minimum	34.1347994	Minimum	32.990038	Minimum	34.574015	Minimum	34.23532
CG	Maximum	34.9996743	Maximum	35.0	Maximum	35.0	Maximum	34.99996
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	122955.298	Mean	123573.25	Mean	123777.93	Mean	124114.2
Weight	Minimum	120356.9	Minimum	122560.9	Minimum	121827.9	Minimum	123563.9
Weight	Maximum	126789.694	Maximum	124649.9	Maximum	124605.79	Maximum	124501
Ballast Weight	Mean	332.103209	Mean	7.9694923	Mean	311.07185	Mean	24.35418
Ballast Weight	Minimum	0	Minimum	0	Minimum	0	Minimum	0
Ballast Weight	Maximum	771.793865	Maximum	262.99325	Maximum	528.65822	Maximum	71.65119
Ballast Weight	Count	285	Count	33	Count	10	Count	5
Ballast Weight	AC req ballast	275	AC req ballast	1	AC req ballast	8	AC req ballast	2

In many regards the CGs and weights in Table 14 and Table 15 are a reflection of Table 7 and Table 8 (which show minimum fuel only); however, the addition of ballast weight at the bottom of these tables adds information about how much weight would need to be added to the various fleet categories by block type (weight added to station 178). If the feasibility report currently being conducted by Boeing, were to determine the capacity of station 178 is less than 1,414 lbs (maximum requirement for weight ballast) and there was no other suitable location to place that much ballast a reexamination of the Block 30 aircraft ballast would need to be conducted, assuming no equipment ballast was to be used. Similarly the maximum ballast requirement in the Block 40 aircraft is slightly less at approx 1,103 lbs (Table 15). Not surprisingly all of these maximum ballast weights are required by aircraft in the KC-135R fleet category.

Aircraft with Minimum Main Tank Fuel & Minimum Trim Ballast (with Armor)

Aircraft examined by fleet segment with minimum fuel in the main tanks (600 lbs in main tanks 1-4) and minimum required trim ballast applied at station 178 (under the radome) to achieve a CG of 35% MAC or less with cockpit armor (treatment B), garnered the following results. Table 17 shows the results for Block 30 aircraft; Table 18 shows the Block 40 aircraft results and Table 19 shows the results for all Block 30 aircraft simulating conversion to Block 40.

Table 17. Treatment B Block 30

	R-Model		T-Model		MPRS		ARR	
Block 30								
CG	Mean	35.0	Mean	33.579474	Mean	34.898422	Mean	34.43773
CG	Minimum	33.9188939	Minimum	32.776795	Minimum	34.361686	Minimum	34.02624
CG	Maximum	35.0	Maximum	35.0	Maximum	35.0	Maximum	34.95824
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	122591.747	Mean	123303.64	Mean	123440.11	Mean	123822.9
Weight	Minimum	120090	Minimum	122294	Minimum	121561	Minimum	123297
Weight	Maximum	126419.218	Maximum	124383	Maximum	124249.43	Maximum	124184
Ballast Weight	Mean	235.452329	Mean	5.2602583	Mean	240.15145	Mean	0
Ballast Weight	Minimum	0	Minimum	0	Minimum	0	Minimum	0
Ballast Weight	Maximum	668.217905	Maximum	173.58852	Maximum	439.56562	Maximum	0
Ballast Weight	Count	285	Count	33	Count	10	Count	5
Ballast Weight	AC req ballast	265	AC req ballast	1	AC req ballast	7	AC req ballast	0

Table 18. Treatment B Block 40

	R-Model		T-Model		MPRS		ARR	
Block 40								
CG	Mean	34.837323	Mean	33.016437	Mean	34.84928	Mean	34.09567
CG	Minimum	33.8620101	Minimum	32.165898	Minimum	34.143327	Minimum	33.94988
CG	Maximum	35.0	Maximum	34.956808	Maximum	35.0	Maximum	34.24147
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	123039.545	Mean	123929.01	Mean	124074.43	Mean	124858.3
Weight	Minimum	121566	Minimum	122876	Minimum	123228	Minimum	124494.5
Weight	Maximum	124105	Maximum	124454.6	Maximum	124883.6	Maximum	125222
Ballast Weight	Mean	49.5757585	Mean	0	Mean	34.003213	Mean	0
Ballast Weight	Minimum	0	Minimum	0	Minimum	0	Minimum	0
Ballast Weight	Maximum	355.199553	Maximum	0	Maximum	142.7277	Maximum	0
Ballast Weight	Count	55	Count	21	Count	10	Count	2
Ballast Weight	AC req ballast	22	AC req ballast	0	AC req ballast	5	AC req ballast	0

Table 19. Treatment B Block 30 Converted

	R-Model		T-Model		MPRS		ARR	
Block 30 converted								
CG	Mean	34.0428361	Mean	32.111122	Mean	33.956847	Mean	32.95572
CG	Minimum	32.3960301	Minimum	31.300175	Minimum	32.853052	Minimum	32.54864
CG	Maximum	34.9994484	Maximum	33.896847	Maximum	34.523347	Maximum	33.47394
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	123473.308	Mean	124415.28	Mean	124316.86	Mean	124939.8
Weight	Minimum	121206.9	Minimum	123284.9	Minimum	122677.9	Minimum	124413.9
Weight	Maximum	126900.181	Maximum	125499.9	Maximum	125337.5	Maximum	125300.9
Ballast Weight	Mean	0.11326676	Mean	0	Mean	0	Mean	0
Ballast Weight	Minimum	0	Minimum	0	Minimum	0	Minimum	0
Ballast Weight	Maximum	32.2810254	Maximum	0	Maximum	0	Maximum	0
Ballast Weight	Count	285	Count	33	Count	10	Count	5
Ballast Weight	AC req ballast	1	AC req ballast	0	AC req ballast	0	AC req ballast	0

Table 17, Table 18 and Table 19 illustrate both the amount of trim ballast that would need to be applied to the front of the aircraft (station 178) and the number of

aircraft that would require ballast above and beyond cockpit armor. The Block 30 aircraft would require the greatest amount of average ballast and the greatest number of aircraft requiring this "trim weight" resides in this fleet segment. In fleet segment I (KC-135R Block 30) 265 of 285 aircraft equipped with cockpit armor would require additional ballast, the most poorly ballasted aircraft requiring an additional 668 lbs be applied at station 178. In fleet segment X (KC-135T Block 30) only 1 of 33 aircraft requires weight be applied at station 178 (173 lbs), when cockpit armor is used. The fleet segment IV (MPRS Block 30) aircraft when equipped with armor require that 7 of the 10 aircraft receive additional ballast to bring the CG forward of 35% MAC. The only Block 30 fleet segment that does not require any additional ballasting, when cockpit armor is used is fleet segment VII (AAR) all 5 aircraft have a CG forward of 35% MAC. Interestingly enough if all of the Block 30 fleet segment aircraft are converted to Block 40 aircraft cockpit armor satisfies the requirement of producing a CG forward of 35% MAC in 332 of the 333 aircraft. The remaining aircraft can be ballasted with approximately 32 lbs of ballast at station 178.

The Block 40 aircraft responded more favorably to the application of cockpit armor than the Block 30 aircraft. Within fleet segment II (KC-135R Block 40) only 22 of the 55 aircraft required additional ballast to bring the airframes within limits and none of the fleet segment XI and VIII (KC-135T Block 40 and AAR Block 40) aircraft required additional ballast beyond cockpit armor. The fleet segment V (MPRS Block 40) aircraft found 5 of the 10 aircraft still required additional ballast.

If one were to assume all Block 40 aircraft (both those currently in this block configuration and the Block 30 aircraft, following their planned upgrade) and the use of

cockpit armor on all of these aircraft, only 28 aircraft in the entire KC-135 fleet would require additional ballast at station 178! If assuming an all Block 40 aircraft solution, it is also notable that the maximum required ballast weight is reduced to approximately 355 lbs at station 178, this eliminates any capacity concerns for station 178, based on T-model ballast.

Aircraft, Minimum Fuel & 3,500 lbs of Fuel in Fwd Body (current configuration)

Research results for aircraft by fleet segment with minimum fuel in the main tanks (600 lbs in main tanks 1-4) and 3,500 lbs of fuel in the forward body tank for ballast (treatment A) as prescribed by EA 08-043-135AMC (Data Revision). Table 20 shows the results for Block 30 aircraft; Table 21 shows the Block 40 aircraft results and Table 22 shows the results for all Block 30 aircraft simulating conversion to Block 40.

Table 20. Treatment A Block 30 (3,500 lbs)

	R-Model		T-Model		MPRS		ARR	
Block 30								
CG	Mean	32.8280129	Mean	30.928653	Mean	32.750964	Mean	31.76794
CG	Minimum	31.1791165	Minimum	30.125021	Minimum	31.644909	Minimum	31.36636
CG	Maximum	33.8771117	Maximum	32.681759	Maximum	33.316297	Maximum	32.28174
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	125006.295	Mean	125948.38	Mean	125849.96	Mean	126472.9
Weight	Minimum	122740	Minimum	124818	Minimum	124211	Minimum	125947
Weight	Maximum	128401	Maximum	127033	Maximum	126870.6	Maximum	126834
Weight	Count	285	Count	33	Count	10	Count	5

Table 21. Treatment A Block 40 (3,500 lbs)

	R-Model		T-Model		MPRS		ARR	
Block 40								
CG	Mean	32.2543743	Mean	30.378611	Mean	32.252266	Mean	31.45466
CG	Minimum	31.1560018	Minimum	29.550391	Minimum	31.483744	Minimum	31.30437
CG	Maximum	33.1407943	Maximum	32.285907	Maximum	32.662156	Maximum	31.60496
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	125639.969	Mean	126579.01	Mean	126690.43	Mean	127508.3
Weight	Minimum	124216	Minimum	125526	Minimum	125878	Minimum	127144.5
Weight	Maximum	126755	Maximum	127104.6	Maximum	127509	Maximum	127872
Weight	Count	55	Count	21	Count	10	Count	2

Table 22. Treatment A Block 30 Converted (3,500 lbs)

	R-Model		T-Model		MPRS		ARR	
Block 30 converted								
CG	Mean	31.3741373	Mean	29.50226	Mean	31.307414	Mean	30.34009
CG	Minimum	29.7135418	Minimum	28.702624	Minimum	30.192385	Minimum	29.9427
CG	Maximum	32.4523285	Maximum	31.22704	Maximum	31.874577	Maximum	30.85162
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	126123.195	Mean	127065.28	Mean	126966.86	Mean	127589.8
Weight	Minimum	123856.9	Minimum	125934.9	Minimum	125327.9	Minimum	127063.9
Weight	Maximum	129517.9	Maximum	128149.9	Maximum	127987.5	Maximum	127950.9
Weight	Count	285	Count	33	Count	10	Count	5

The CGs found on these tables are all forward of 35% MAC, this is in fact the current configuration. The inclusion of these tables is primarily as a reference point or control treatment against which all other treatments will be compared. The mean weights are of the greatest interest, because they represent the starting point for all weight reduction proposed in this study. The current fuel use and costs will be calculated using this data for each fleet segment for comparison with those of the different treatments to determine fuel and cost mitigation. The aft-most CG found on Table 20 is 33.87% MAC

(aircraft 57-1462) and not 35% MAC because EA 08-043-135AMC (Data Revision) applied the entire weight of a 3 person crew at station 1300 and this study did not.

Aircraft, Minimum Fuel & 2,000 lbs of Fuel in Fwd Body (Block 40)

The following is an examination of Block 40 and Block 30 aircraft simulating conversion to Block 40 aircraft by fleet segment with minimum fuel in the main tanks (600 lbs in main tanks 1-4) and 2,000 lbs of fuel in the forward body tank for ballast (treatment A). Since the controlling aircraft (57-1462) driving the requirement for 3,500 lbs of fuel in the forward body as prescribed by EA 08-043-135AMC (Data Revision) was a Block 30 it seemed logical to find out what the minimum fuel requirement would be for a Block 40 only fleet. Table 23 shows the results for Block 40 aircraft and Table 24 shows the results for all Block 30 aircraft simulating conversion to Block 40 (using weight and balance correction).

Table 23. Treatment A Block 40 (2,000 lbs)

	R-Model		T-Model		MPRS		ARR	
Block 40								
CG	Mean	34.1221867	Mean	32.2099	Mean	34.104376	Mean	33.28524
CG	Minimum	33.0320319	Minimum	31.368575	Minimum	33.327001	Minimum	33.13844
CG	Maximum	35.0	Maximum	34.134784	Maximum	34.514763	Maximum	33.43205
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	124139.969	Mean	125079.01	Mean	125190.43	Mean	126008.3
Weight	Minimum	122716	Minimum	124026	Minimum	124378	Minimum	125644.5
Weight	Maximum	125255	Maximum	125604.6	Maximum	126009	Maximum	126372
Weight	Count	55	Count	21	Count	10	Count	2

Table 24. Treatment A Block 30 Converted (2,000 lbs)

	R-Model		T-Model		MPRS		ARR	
Block 30 converted								
CG	Mean	33.2241259	Mean	31.315998	Mean	33.14418	Mean	32.15622
CG	Minimum	31.5773944	Minimum	30.510756	Minimum	32.039896	Minimum	31.75323
CG	Maximum	34.2658515	Maximum	33.078012	Maximum	33.709364	Maximum	32.67097
CG	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0
Weight	Mean	124623.195	Mean	125565.28	Mean	125466.86	Mean	126089.8
Weight	Minimum	122356.9	Minimum	124434.9	Minimum	123827.9	Minimum	125563.9
Weight	Maximum	128017.9	Maximum	126649.9	Maximum	126487.5	Maximum	126450.9
Weight	Count	285	Count	33	Count	10	Count	5

Table 23 and Table 24 simply serve to prove that should a "fuel solution" continue to be pursued to ballast the KC-135 fleet that 2,000 lbs of fuel instead of 3,500 lbs of fuel is adequate for all Block 40 aircraft. This is logical due to the additional equipment added to all Block 40 aircraft, 1,116.9 lbs with a longer moment-arm than the forward body tank. It can be considered that Block 40 equipment serves as a partial equipment ballast solution 1,116.9 lbs added to remove 1,500 lbs of fuel, saving approx 383 lbs total weight.

Modification Calculations

Table 25 shows the number of aircraft requiring additional ballast by fleet segment, given various conditions. These numbers are used to determine fleet modification cost.

Table 25. Fleet Segment Ballast Requirements

		R-Model		T-Model		MPRS		ARR		Total w/CG>35
Empty (no ballast)	**Block 30**	AC w/CG >35.0	285	AC w/CG >35.0	30	AC w/CG >35.0	10	AC w/CG >35.0	5	330
Empty (no ballast)	**Block 40**	AC w/CG >35.0	55	AC w/CG >35.0	6	AC w/CG >35.0	10	AC w/CG >35.0	2	73
Min Fuel in Mains (no ballast)	**Block 30**	AC w/CG >35.0	285	AC w/CG >35.0	27	AC w/CG >35.0	10	AC w/CG >35.0	5	327
Min Fuel in Mains (no ballast)	**Block 40**	AC w/CG >35.0	55	AC w/CG >35.0	3	AC w/CG >35.0	10	AC w/CG >35.0	2	70
Min Fuel in Mains (no ballast)	Block 30 converted	AC w/CG >35.0	275	AC w/CG >35.0	1	AC w/CG >35.0	8	AC w/CG >35.0	2	286
Min Fuel in Mains/cockpit armor & no additional ballast	**Block 30**	AC w/CG >35.0	265	AC w/CG >35.0	1	AC w/CG >35.0	7	AC w/CG >35.0	0	273
Min Fuel in Mains/cockpit armor & no additional ballast	**Block 40**	AC w/CG >35.0	22	AC w/CG >35.0	0	AC w/CG >35.0	5	AC w/CG >35.0	0	27
Min Fuel in Mains/cockpit armor & no additional ballast	Block 30 converted	AC w/CG >35.0	1	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	1
Min Fuel in Mains and 3500 lbs of fuel in Fwd Body tank (current config)	**Block 30**	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	0
Min Fuel in Mains and 3500 lbs of fuel in Fwd Body tank (current config)	**Block 40**	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	AC w/CG >35.0	0	0

Due to the ongoing upgrade of aircraft within all categories from Block 30 to Block 40, it would be difficult to calculate modification and return on investment for the Block 30 fleet. What does make sense is to calculate the modification and return based on an all Block 40 fleet. This was done by using the Block 40 and Block 30 (converted) data. To operationally execute these potential solutions, Block 40 guidance with regard to fuel loading will have to diverge from Block 30 guidance until all remaining Block 30 aircraft are upgraded or retired.

Solution Sets

Based on the Block 40 only scenario, the solution sets are:

1.) **Continue using 3,500 lbs of fuel ballast in the Forward Body tank**

2.) **Reduce Forward Body tank fuel ballast to 2,000 lbs**

3.) **Equip the entire KC-135 fleet with cockpit armor (421 aircraft) and apply ballast "trim weight" to 28 aircraft**

4.) **Use "weight ballast" to ballast the entire fleet requiring ballasting (356 aircraft)**

5.) **Hybrid solution of equipping all MPRS and AAR aircraft with cockpit armor (27 aircraft) and applying "trim weight" to the 5 MPRS birds that would still require more ballast and then using "weight ballast" to reballast the rest of the fleet requiring ballast (334 aircraft)**

Modification cost for each solution set calculated as:

1.) **Continue using 3,500 lbs of fuel ballast in the Forward Body tank**

3,500 lbs X $0.47 per pound = $1,647 per aircraft

$1,647 per aircraft X 421aircraft = <u>$692,545 total solution 1 modification cost (also total control modification cost)</u>

(Cost of fuel used to ballast aircraft must be considered because like any other form of ballast it cannot be used for any other purpose)

2.) **Reduce Forward Body tank fuel ballast to 2,000 lbs**

2,000 lbs X $0.47 per pound = $940 per aircraft

$940 per aircraft X 421 aircraft = <u>$395,740 total solution 2 modification cost</u>

3.) **Equip the entire KC-135 fleet with cockpit armor (421 aircraft) and apply ballast "trim weight" to 28 aircraft**

$82,500 (kit cost) X 421aircraft = $34,732,500 recurring cockpit armor cost

$34,732,500 recurring cockpit armor cost + $82,500 non-recurring cost = $34,815,000 total cost for KC-135 cockpit armor

$51,000 weight ballast cost per aircraft X 28 aircraft = $1,428,000 cost to add weight ballast

$34,815,000 + $1,428,000 = <u>$36,243,000 total solution 3 modification cost</u>

4.) **Use "weight ballast" to ballast the entire fleet requiring ballasting (356 aircraft)**

$51,000 X 356 aircraft = <u>$18,156,000 total solution 4 modification cost</u>

5.) **Hybrid solution of equipping all MPRS and AAR aircraft with cockpit armor (27 aircraft) and applying "trim weight" to the 5 MPRS birds that would still require more ballast and then using "weight ballast" to reballast the rest of the fleet requiring ballast (334 aircraft)**

$82,500 (kit cost) X 27 aircraft = $2,227,500 recurring cockpit armor cost

$2,227,500 recurring cockpit armor cost + $82,500 non-recurring cost = $2,310,000 total cost for cockpit armor

$51,000 X 339 aircraft = $17,289,000 cost to add weight ballast

$2,310,000 + $17,289,000 = <u>$19,599,000 total solution 5 modification cost</u>

Average Aircraft Weight Difference by Solution Set

The aircraft weight differences for each solution set are calculated by determining the population's mean weight in our control group ($\mu_{\text{control weight}}$) then subtracting the new population mean weight ($\mu_{\text{solution x weight}}$) to determine weight difference for the solution set ($\Delta_{\text{ solution x weight}}$). Since aircraft weight means are calculated by fleet segment, the following equation is used to calculate weighted means (not to be confused with mean weights):

Equation 1

where

x_i = mean aircraft weight given fleet segment i

w_i = number of aircraft in fleet segment i

Equation 2

where

Once weight difference for the solution set ($\Delta_{\text{ solution x weight}}$) is determined, hourly fuel mitigation can be determined in lbs of fuel (JP-8) by multiplying weight difference by CoW for the KC-135 ($\text{CoW}_{\text{KC-135}}$):

Equation 3

$\Delta_{\text{ solution x weight}}$ X $\text{CoW}_{\text{KC-135}}$ = Solution x Hourly Fuel Mitigation

and

$\text{CoW}_{\text{KC-135}}$ = .0497 lbs of fuel burned per lb carried per hr of flight

Solution x fuel cost mitigation is the product of Solution x hourly fuel mitigation and the cost per pound of JP-8:

Equation 4

Solution x Hourly Fuel Mitigation X $0.47 per lb of fuel = Solution x Hourly Fuel Cost Mitigation

1.) **Continue using 3,500 lbs of fuel ballast in the Forward Body tank**

This solution set is also the control, so population's mean weight in our control group ($\mu_{\text{control weight}}$), will equal solution 1 population mean weight ($\mu_{\text{solution 1 weight}}$). Mean fleet segment weights used below come from Table 21 Block 40 aircraft and Table 22 Block 30 aircraft simulating conversion to Block 40 (using weight and balance).

$\mu_{\text{control weight}}$ = 126,214.15 lbs (Equation 1)

$\Delta_{\text{solution 1 weight}}$ = 0 lbs (by definition) (Equation 2)

0 lbs of fuel per hr = Solution 1 Hourly Fuel Mitigation (Equation 3)

$0.00 per hour = Solution 1 Hourly Fuel Cost Mitigation (Equation 4)

2.) **Reduce Forward Body tank fuel ballast to 2,000 lbs**

Mean fleet segment weights used below come from Table 23 and Table 24.

$\mu_{\text{solution 2 weight}}$ = 124,714.15 lbs (Equation 1)

$\Delta_{\text{solution 2 weight}}$ = 1,500 lbs (Equation 2)

74.55 lbs per hr = Solution 2 Hourly Fuel Mitigation (Equation 3)

$35.04 per hour = Solution 2 Hourly Fuel Cost Mitigation (Equation 4)

3.) Equip the entire KC-135 fleet with cockpit armor (421 aircraft) and apply ballast "trim weight" to 28 aircraft

Mean fleet segment weights used below come from Table 18 and Table 19.

$\mu_{\text{solution 3 weight}}$ = 123,571.51 lbs (Equation 1)

$\Delta_{\text{solution 3 weight}}$ = 2,642.64 lbs (Equation 2)

131.33 lbs per hr = Solution 3 Hourly Fuel Mitigation (Equation 3)

$61.73 per hr = Solution 3 Hourly Fuel Cost Mitigation (Equation 4)

4.) Use "weight ballast" to ballast the entire fleet requiring ballasting (356 aircraft)

Mean fleet segment weights used below come from Table 15 and Table 16.

$\mu_{\text{solution 4 weight}}$ = 123,063.00 lbs (Equation 1)

$\Delta_{\text{solution 4 weight}}$ = 3,151.15 lbs (Equation 2)

156.61 lbs per hr = Solution 4 Hourly Fuel Mitigation (Equation 3)

$73.61 per hr = Solution 4 Hourly Fuel Cost Mitigation (Equation 4)

5.) Hybrid solution of equipping all MPRS and AAR aircraft with cockpit

armor (27 aircraft) and applying “trim weight” to the 5 MPRS birds that would still require more ballast and then using “weight ballast” to reballast the rest of the fleet requiring ballast (334 aircraft)

Mean fleet segment weights used below come from Table 15 for fleet segments II and XI (KC-135R and KC-135T) aircraft, Table 18 for fleet segments V and VIII (MPRS and AAR) aircraft, Table 16 for fleet segments III and XII (KC-135R and KC-135T) aircraft and Table 19 for fleet segments VI and IX (MPRS and AAR) aircraft. The fleet segmentation approach allows this type of hybrid solution to be examined by using the mean weight from the applicable tables and compiling them into a weighted mean.

$\mu_{\text{solution 5 weight}}$ = 123,092.30 lbs (Equation 1)

$\Delta_{\text{ solution 5 weight}}$ = 3,121.85 lbs (Equation 2)

155.15 lbs per hr = Solution 5 Hourly Fuel Mitigation (Equation 3)

$72.92 per hr = Solution 5 Hourly Fuel Cost Mitigation (Equation 4)

Recoupment Horizon Calculation by Solution Set

Fiscal analysis must evaluate each solution set against the same parallel and quantifiable scale. The metric chosen for this study was the recoupment horizon. The recoupment horizon determines the number of years of operation, given increased efficiency; it takes for each solution set’s requisite modifications to pay for themselves. This simply measures money and does not consider non-monetary considerations which are discussed later.

Recoupment horizons for each solution set were calculated using Equation 5.

Equation 5

where

Equation 6

and

Equation 7

As discussed earlier the annual flight hours for the KC-135 fleet are 200,367 hrs/year.

1.) Continue using 3,500 lbs of fuel ballast in the Forward Body tank

= **Indefinite Recoupment Horizon for Solution Set 1** (Equation 5)

Since solution set 1 is also the control group there is no breakeven point, nor is there any increased efficiency after the horizon has passed.

2.) Reduce Forward Body tank fuel ballast to 2,000 lbs

= **-.042 years** (Equation 5)

Because solution set 2 is less expensive to enact than the control group and there is an increased efficiency over the control group the recoupment horizon is negative.

3.) **Equip the entire KC-135 fleet with cockpit armor (421 aircraft) and apply ballast "trim weight" to 28 aircraft**

$= \underline{\mathbf{2.874\ years}}$ (Equation 5)

Since the modification costs associated with this solution set are the highest the recoupment horizon's longer duration is logical.

4.) **Use "weight ballast" to ballast the entire fleet requiring ballasting (356 aircraft)**

$= \underline{\mathbf{1.184\ years}}$ (Equation 5)

The relatively short recoupment horizon for this solution set is due to the highest solution fuel cost mitigation rate.

5.) **Hybrid solution of equipping all MPRS and AAR aircraft with cockpit armor (27 aircraft) and applying "trim weight" to the 5 MPRS birds that would still require more ballast and then using "weight ballast" to reballast the rest of the fleet requiring ballast (334 aircraft)**

$= \underline{\textbf{1.294 years}}$ (Equation 5)

Solution set 5 has a slightly longer recoupment horizon than solution set 4 due to a marginally higher modification cost and slightly lower fuel cost mitigation rate. A synopsis of recoupment horizons is shown in Table 26.

Table 26. Recoupment Horizons

Solution Set	Recoupment Horizon
1	N/A
2	-.042 years
3	2.874 years
4	1.184 years
5	1.294 years

V. Discussion

Objective Evaluation

The analysis of this study must include more than just consideration of recoupment horizons, while a valuable and quantifiable metric, mitigating cost was only one of the objectives stated. The other objectives were to increase mission capability, decrease U.S. dependence on foreign energy, mitigate pollution/GHG emissions, and compliance with stated goals set forth by President Bush and Air Force Secretary Donley. Evaluation of the solution sets against each of these criteria helps frame overall validity

of the solution.

The discussion of mission capability as it pertains to this study is multi-faceted. There are numerous mission capability implications found among the various solution sets. The most dramatic are increased fuel offload capability, lighter aircraft gross-weight for a given mission (decreasing runway length requirements), and increased aircrew protection from cockpit armor (allowing for forward deployment of aircraft).

The increased offload capability offered by solution sets 3, 4 and 5 is an additional 3,500 lbs of fuel per mission; this is due to removing the requirement to store unusable fuel in the forward body tank. Solution set 2 increases offload capability by 1,500 lbs of fuel by reducing the requirement to store fuel in the forward body tank from 3,500 lbs to 2,000 lbs. The increased offload capability is further increased by the decreased burn rate that each of these solution sets offer over the course of each individual mission. Additionally, the possibility exists that by increasing fuel offload capability it may be possible to decrease the number of sorties needed to deliver fuel required in some cases.

Decreased aircraft gross weight, offered by solution sets 3, 4, 5, and to a lesser extent solution set 2, accomplishes more than just reducing fuel burn rate. Lighter aircraft are capable of taking off and landing on shorter airfields and climbing at increased rates. The capability to operate out of shorter air fields and air fields requiring a higher climb gradient increases basing options for planners and may decrease mission duration if it results in closer options.

The aircrew protection from cockpit armor offered by solution sets 3 and 5 when combined with large aircraft infrared countermeasures (LAIRCM), already planned for

the KC-135 fleet (beginning with 22 KC-135s to support special missions), satisfies Threat Working Group (TWG) requirements for defensive systems for high threat airfields (Air Mobility Command, 2008: 80). This will increase the KC-135 forward operation capability significantly, decreasing average mission duration and further increasing offload capability.

Decreased U.S. dependence on foreign energy, mitigation of pollution/GHG emissions, and compliance with stated goals all are a direct correlation to the decreased fuel burn rates offered by solution sets 2, 3, 4, and 5. Irrespective of recoupment horizon, which considers initial modification costs and fuel cost, these objective are best evaluated against solution hourly fuel mitigation listed below:

74.55lb/hr = Solution 2 Hourly Fuel Mitigation

131.33lb/hr = Solution 3 Hourly Fuel Mitigation

156.61lb/hr = Solution 4 Hourly Fuel Mitigation

155.15lb/hr = Solution 5 Hourly Fuel Mitigation

Obviously solution set 4 closely followed by solution set 5 do the best job of complying with these objectives, but it must be noted that solution set 3 still offers a marked improvement over the control group while making a mission valuable contribution with its ballast.

Recommendation for Implementation

The need to implement some measure to correct the vast inefficiencies created by the slow and insidious weight and CG creep experienced by the KC-135 airframe is clear, but which measure should be taken? Numerous options are posited within this study in the form of solution sets, but any number of hybrid solutions could be developed along

fleet segment lines to meet various objectives. The author's suggestion for implementation is a phased approach comprised of a short-term, mid-term and long-term fix.

Short-term:

Issue Block 40 specific guidance (GM to 11-2-KC-135 Vol. 3) reducing the "zero fuel" requirement on Block 40 aircraft to 4,400 lbs (2 000 lbs in the forward body for ballast) while keeping the Block 30 requirement at 5,900 lbs. In addition to this change, the GM should provide a clearer explanation as to the makeup of the "zero fuel" prescribed, specifying 600 lbs per main tank and the amount that must remain in the forward body for ballast (this was not made clear enough in GM1). This will increase efficiency, decrease operating cost, increase offload capability and requires no modification to the aircraft (Solution Set 2).

Mid-term:

Equip all MPRS and AAR Block 40 aircraft with cockpit armor and add nose-ballast to those few that require it, and then issue a GM to reducing "zero fuel" to 2,400 lbs of fuel for those fleet segments. This will expand the operational capability of these aircraft and make them even more capable in their diverse missions supporting international, joint and special operations forces. This will increase efficiency within the MPRS and AAR Block 40 fleet segments as well as vastly increasing mission capability. This is a low cost solution since only a handful of aircraft require modification and will serve to validate increased operational capability.

Long-term:

Equip the entire Block 40 fleet with cockpit armor and use trim ballast to "trim" aircraft

requiring it. Once the entire fleet is ballasted and "tankering fuel" for ballast is eliminated, the full benefit described by solution set 3 can be realized. While this solution is the most expensive approximately $38M it can be spread over a couple of years, once all current Block 40 aircraft are armored and ballasted the process will be tied to the Block upgrade of all remaining aircraft.

Areas for Future Research

The future programmed "block upgrades" to the KC-135, Block 45 and Block 50, will require weight and balance evaluation, when the equipment to be included in those upgrades is finalized. This analysis should become part of all aircraft upgrades to ensure situations, such as the one created in the KC-135 community, do not occur in the future. An evaluation of aircraft fleet compliance with the SECAF's goal stated in AFPM 10-1 "of reducing aviation fuel-use per hour of operation by 10% (from a 2005 base line) by 2015" (Donley, 2009) should be conducted to determine the Air Force's progress.

If solution set 3 is implemented, a study should be conducted to evaluate mission sortie duration of forward based tankers and an examination of shorter field length capabilities. A potential classified study could be conducted to determine if Operational Plans (OPLANS) could be modified based on increased KC-135 mission capabilities, specifically increased offload capability.

Conclusion

The KC-135 has been the backbone of the USAFs global reach for over half a century. The small adjustments required to return the weight and balance of this airframe

to where it needs to be will pay for themselves financially in a very short period of time and increase the capability of this “old warhorse” to fight the nation’s wars well into the future. The problems that led up to the current CG issues are the result of numerous small changes, this study supports making one more small change to fix the cumulative unintended consequences of those previous changes. The times when fuel was cheap and the USAF had excess air refueling capability are behind us, today it is vital that we make efficient use of the resources we have at our disposal. This study has endeavored to provide the tools to Air Force leadership to make informed and insightful decisions regarding the KC-135 fleet so that it may be used both more efficiently and effectively in the future. The increased fuel offload provided by fleet modification can offer every Combatant Commander who requires tanker support more of a resource that is in critically short supply.

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Vita

Major Philip G. Morrison is a graduate of the United States Air Force Academy, where he earned a B.S. in Military History in 1998. After graduating from the USAF Academy he attended Undergraduate Pilot Training at Columbus AFB earning his wings in 1999. Major Morrison has served two operational tours flying the KC-135 at Grand Forks AFB, ND and MacDill AFB, FL. He has also worked as a Tanker Planner at the 618 TACC and most recently as the Chief KC-135 Command Evaluator for AMC. While working in his last position Major Morrison was tasked with evaluating Air Mobility Command's fuel efficiency and developing ways of mitigating fuel use by the USAF mobility fleet. He holds an M.S. in International Relations from Troy University and is currently a student enrolled in the Air Force Institute of Technology's M.S. in Logistics program as part of the Advanced Study of Air Mobility professional education course. Major Morrison's next assignment is to the Pentagon, where he will be the Air Force Tanker Requirements Branch Chief.

BLue Dart Submission Form

First Name: __Philip________________ Last Name: __Morrison_________________

Rank (Military, AD, etc.): __Major_________ Designator #AFIT/IMO/ENS/10-10

Student's Involved in Research for Blue Dart:____________________________________

____

Position/Title: __Student___ ____

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School/Organization: _Advanced Study of Air Mobility (ASAM)_________________

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[ ] warfighting	[ ] international security	[ ] doctrine

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Suggested Headline: How flying lead bricks around can save fuel and increase the offload capability of the KC-135 fleet______________________________

Keywords: Fuel Efficiency, KC-135, Ballast, Cockpit Armor and Increased Fuel Offload Capability

Blue Dart:

Every time a KC-135 takes off its mission is handicapped and it costs the taxpayers far more than it should. This isn't as one may assume because it is an old aircraft that lacks the technological advances that a newer aircraft enjoys, ironically it is because great care has been taken to keep the KC-135 a viable mission platform that it suffers this penalty. The good news is a very old fashioned remedy can fix the problem

saving tens of millions of dollars a year and increase offload capability by almost two percent.

The KC-135 was subject to numerous changes over its first 50 years of service as it has adapted to new and expanded mission requirements. These changes have added a large amount of weight to the aircraft, much of it focused in the rear of the airframe which created an aft Center of Gravity (CG). Boeing accounts for this aft CG by requiring that ballast fuel be carried in the forward body tank to maintain a CG forward of the aft limit.

An Engineering Analysis (EA) recently performed by Boeing states that 3,500 lbs of fuel is to be left in the forward body tank strictly for ballast, with no other purpose. Using fuel in the forward body tank for ballast has two significant drawbacks; the forward body tank has a very short moment-arm necessitating more weight than that of ballast on a longer moment-arm, and ballast fuel displaces fuel that could be used for mission purposes by using the tank to hold ballast weight.

Reducing aircraft gross weight is a cost issue, because excess weight incurs a "carriage cost". The "carriage cost" for weight on the KC-135 is 4.97% of the weight in pounds of fuel burned per hour. Research shows that replacement of fuel ballast with lead ballast on a longer moment arm or using weight with a mission purpose, in the form of cockpit armor, minimizes ballast weight requirements. This reduces aircraft gross weight and generates increased fuel efficiency.

To equip the KC-135 fleet with simple ballast in the form of lead bricks it would cost just over $18M, but increased efficiency would pay for that fleet-wide modification in 1.1 years. If the Air Force chose to use cockpit armor to ballast out the KC-135

instead, it would cost just over $36M and take approximately 2.8 years to recoup modification costs. The concern that the KC-135 is a legacy aircraft is valid. Pouring money into a 55 year old airplane may seem wasteful, but Air Mobility Command (the agency responsible for programming the KC-135 fleet) projects the KC-135 fleet will be flying for at least another 30 years and even the most extravagant reballasting proposal would pay for itself in less than 3 years. Those who suggest we don't modify the KC-135 are essentially saying 27 years of saving $12-18M a year isn't fiscally sound!

The question of whether to use cockpit armor to ballast the KC-135 fleet or to use the cheaper method utilizing lead bricks to ballast the aircraft, hinges on what capability the KC-135 needs. The KC-135 has been placed increasingly further forward in an effort to enhance the effectiveness of its vital air refueling capability, but with no increased defenses. Large Aircraft Infrared Counter Measures (LAIRCM) are now being purchased for the KC-135 fleet, the addition of cockpit armor in concert with LAIRCM would allow for an even greater forward basing option.

Regardless of which ballast option is used, the removal of 3,500 lbs of ballast fuel allows for an additional offload capability of 3,500 lbs of fuel in addition to the fuel cost savings. The tax payers deserve more capability for less money, the simple common sense solutions available to solve this problem are painfully obvious and the supporting data can demonstrate at the individual aircraft level and the fleet level why we need to make these modifications.

Apr 10

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